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REMOTE SENSING CHRONIC OIL DISCHARGES

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by

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1.0 INTRODUCTION

Exploration drilling for oil and gas is currently underway in three major offshore areas within Canada. Production from these areas may begin within the next decade if economic conditions are favourable. The shift from exploration to production phase will result in a dramatic increase in the amount of hydrocarbon products stored, processed and handled at offshore facilities. The risk of oil discharges into the water column will increase correspondingly.

A 'sentinel' oil monitoring system is being considered as a means of remotely sensing oil discharges via instrumentation mounted on the rig or production platform. Such a system would monitor the water surface in the vicinity of the offshore platform for oil films, and trigger an alarm when a significant oil film was detected. The system would be required to have a low false alarm rate and the ability to operate under a wide range of environmental and illumination conditions.

Considerable effort has been expended over the last several decades in designing suitable systems to detect and measure oil slicks on the water surface. Bercha (1984) detailed a wide range of airborne remote sensing systems that showed good potential. These include photographic cameras, IR-UV scanners, Low Light Level Television (LLLTV), Forward Looking Infrared (FLIR) Devices, microwave sensors, laser fluorosensors as well as a host of other related equipment. Based on the recommendations of this report, a second study (Martec, 1985), was undertaken which field tested five sensor systems. These included:

- a Low Light Level Television (LLLTV) outfitted for detection in the near-UV;
- a pyro-electric vidicon system;
- a Barr and Stroud IR Imager;
- an Oilspills vapour detection device;
- and a 70 mm camera outfitted for detection in the near UV.

A standard 35 mm camera was also used for documentation purposes. The report recommended the pyro-electric vidicon had no application for chronic oil spill detection due to insufficient sensitivity. The LLLTV performed well except had no capability at night where reflected lights caused the camera to reduce its sensitivity. The photographic cameras showed good documentation capabilities but had no real real-time detection capabilities. Operational problems were encountered with both the Barr and Stroud Thermal Imager and the Oilspills sensor, and as a result, a full evaluation of those two units was not possible.

This report presents a literature search of existing sentinel oil detection instruments, and a laboratory and field evaluation of three instruments. The literature search included both floating and short range oil detection devices. The best device from this literature review was then included in the evaluation.

The evaluation examined three oil detection devices:

- a thermal imager (Barr and Stroud Ltd);
- a vapour detector (Moniteq Ltd. 'Oilspills');
- an active infrared sensor (Wright and Wright Inc. 'Infrared Oil Film Monitor').

The Barr and Stroud Thermal Imager was the same instrument as tested in Phase 2 but with a better mount and more effective air filtering system. The Oilspills sensor also had received major changes to the data smoothing and interpretation routines and a better data display system. The third sensor tested was an Infrared Oil Film Monitor manufactured by Wright and Wright Inc. The instrument tested was a relatively new design incorporating a thermo-electrically cooled detector.

The three oil sensing systems were evaluated in both indoor and outdoor testing. The indoor testing was conducted at the Dalhousie University Tower Tank where the sensors were mounted 10 m above the water surface and evaluated under a number of air and water temperature conditions. The outdoor testing was undertaken at the Esso Resources Canada Refinery

located in Dartmouth, Nova Scotia. The sensors were mounted on a moveable platform and elevated over an enclosed area of Halifax Harbour to a height of 20 metres. This permitted testing of the sensors in a wide range of atmospheric and oceanographic conditions.

The sensors were evaluated for their ability to detect a variety of oils under a wide range of environmental and illumination conditions and to generate an alarm signal. Other important factors were mechanical reliability, operational requirements and the ability to generate a reliable alarm signal.

2.0 LITERATURE REVIEW OF SENTINEL OIL MONITORING DEVICES

Whereas airborne remote sensing systems are generally capable of regional areal coverage, this section will consider only those devices capable of 'sentinel' detection of oil slicks by mounting on or near a platform, dock or vessel. Many of the techniques have been designed for deployment in harbours and rivers. In their current stage of development, some of these techniques may not have application offshore, but they will be discussed since they represent novel approaches to oil slick detection.

Most of the information contained in this section was obtained from U.S. Coast Guard reports published during the early to mid 1970's. Since that time, little research has been conducted into the area of sentinel oil surveillance. Wright and Wright are currently the only company actively marketing such a device. Other manufacturers have generally stopped production due to low demand for their products. Low demand is in part due to the limited effectiveness of most of the devices and their high per unit cost. A general lack of regulations in the United States requiring such devices, and the high cost of liability insurance for the manufacturers has not encouraged their deployment.

2.1 Infrared Oil Film Monitors

Infrared oil film monitors are a type of active sensor which illuminates the water-oil surface with a broad band light source and analyses the reflected radiation in two narrow wavebands. They rely on the dramatic shift in the reflectivity of water due to water molecule absorption in the region 2.0 to 4.0 um (see Figure 1). The reflected signal strength in both channels is measured and an OIL/NO OIL is made based on the ratio of these two values.

Since the instrument relies on a received signal reflected from the water surface, the sensor should ideally be mounted such that the optical axis of the receiver is normal to the surface of the water. Positioning the sensor off of the vertical or operation when waves are present on the water surface results in a reduction in received signal because a large percentage of the signal will be reflected away from the receiver optics. A received signal can be assured if the diameter of the illuminated area on the water surface is at least half of the distance between wave crests. In this situation, at least one facet of the wave will be normal to the sensor and a reflected signal will be available at the detector. Atmospheric transmittance and operating height will also have an effect on the amount of the received signal.

Three companies which have built and tested infrared oil film monitors are Texas Instruments, Rambie Inc. and Wright and Wright Inc. The latter two companies marketed their detectors on a commercial basis, but only Wright and Wright is presently in business.

2.1.1 Wright and Wright Infrared Oil Film Monitor

In 1973, Wright and Wright designed and built an infrared oil film monitor that used infrared reflectance at the 3.1 um peak and 2.7 um valley to detect the presence of oil on the water surface. The sensor worked well at a height of 1.8 metres but was unable to operate at higher elevations due to insufficient signal return.

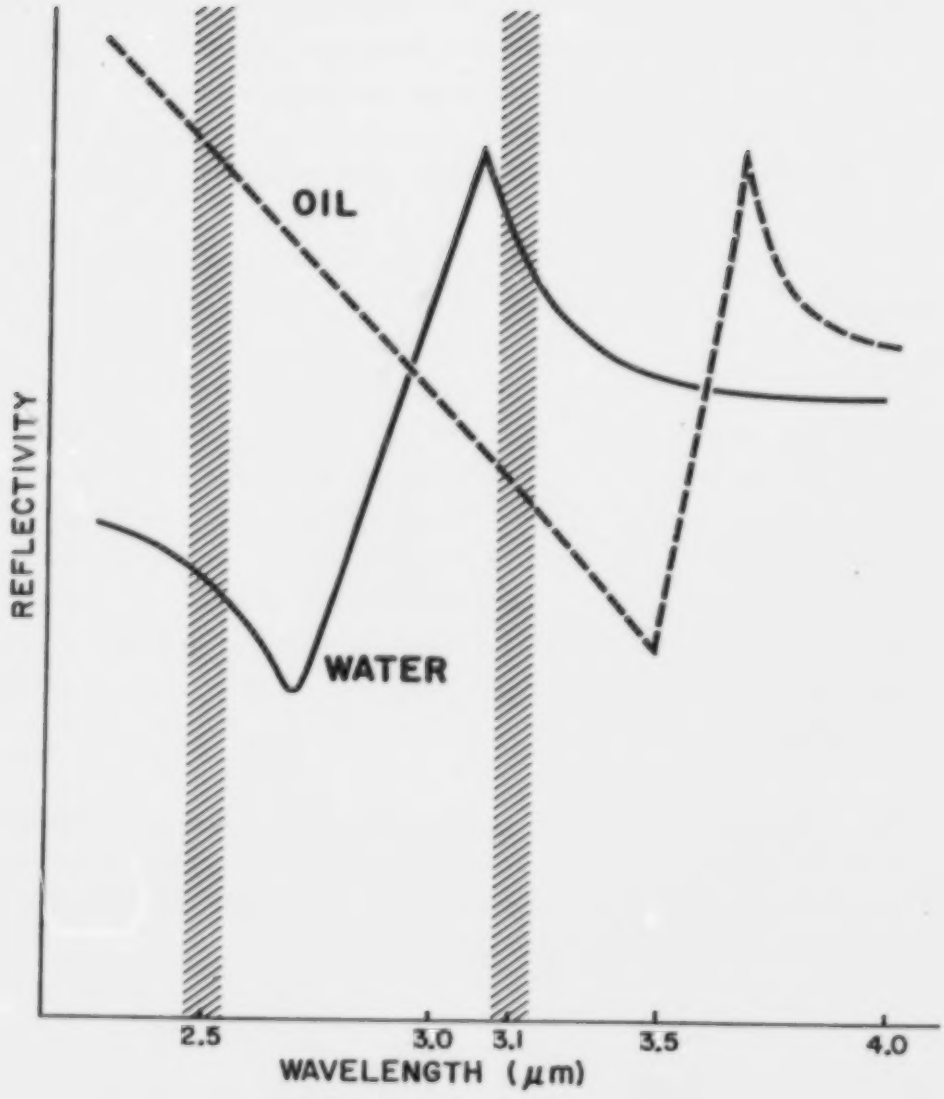


Figure 1. Spectral reflectance of water and oil (wavebands used by Wright and Wright Infrared Oil Film Monitor are shaded areas) (from Flanagan et al., 1975).

A feasibility study (Wright and Wright 1973) was undertaken to make recommendations for an instrument which could operate effectively at a height of 9.1 metres. Although the study was not able to design a prototype completely effective at 9.1 metres, a number of noteworthy modifications and future design considerations were made.

With the old instrument, the problem of water molecule absorption of the transmitted and reflected beam was serious. Detection in the 2.7 um waveband was especially hampered since this was centered in a water vapour absorption band. To reduce the absorption in this band, it was decided to move the band from 2.7 um to 2.5 um where water molecule absorption was less. The wavebands centered at 2.5 um and 3.1 um were those used in the 1976 tests (White, 1976) and are the same as used in the present day instrument.

Other recommendations included increasing the optical aperature of the instrument to increase signal strength. Sensor response could further be increased if two optical paths with separate detectors were used. This would decrease the electro-optical crosstalk between the two channels and quicken instrument response. The current instrument uses a larger optical aperature, however, the dual optical path recommendation was dismissed as being too costly for most applications.

An evaluation of the Wright and Wright oil film sensor was undertaken by the U.S. Coast Guard in New York Harbour from September 1975 through to March 1976 (White, 1976). During this time, the sensor was mounted on a dock at a height of 2.8 metres above mean water with a tidal range of 1.8 metres.

The sensor was effective in detecting oil in most situations; in fact it often detected oil when none was visible on the water surface. Only after laboratory analysis of surface samples were the investigators confirmed the instrument response was indeed correct.

The instrument had considerable difficulty differentiating invisible oil films from sheens and slicks. The investigators found that the relationship

between signal level and oil film thickness was not linear and may be influenced by other factors such as oil type.

The study found the Wright and Wright Oil Film Monitors to be well built and mechanically reliable. The sensor detected oil in all instances but there was a high incidence of alarm when only a very thin or invisible oil film was present on the water surface.

2.1.2 Rambie Oil on Water Sensor

Only limited information is available for this sensor and the company that produced it is no longer in business. The Rambie sensor used a very low power lamp projecting downwards, whose reflected signal was received and filtered for two narrow wavebands centered at 3.4 and 3.8 um. The OIL/NO OIL decision was based on the ratio of signal strengths in the two wavebands.

All information pertaining to the performance of the Rambie Oil on Water Sensor was obtained from White (1976). During the evaluation, the Rambie sensor was mounted alongside the Wright and Wright unit but was found to be much more difficult to set up and maintain. Considerable effort was required during the initial setup since the transmitter and detector required accurate alignment. The individual channel amplifiers were then adjusted to achieve the proper ratio value for clean water. Problems were encountered since ambient oil levels in the area were often high and this did not allow for a correct clean water adjustment.

Once installed, the sensor required constant attention and repair. The sensor was very sensitive to tidal fluctuations, instrument orientation and surface conditions. Although the sensor was able to define very thin oil films invisible to the unaided eye, the unit was mechanically unreliable and produced a large number of false alarms.

2.1.3 Texas Instruments Active Sensor

In the early 1970's, Texas Instruments had an oil spill detector program which designed, built and tested a number of oil detection devices. The information which follows is derived entirely from the study undertaken by Texas Instruments Inc. (Mohr et al., 1973). No independent testing of the Texas Instruments sensors has been conducted, however, the technology was later used in the design of the Rambie sensors, once Texas Instruments stopped development.

Texas Instruments Inc. has built and tested three models of infrared oil film monitors. All work on a principle similar to that described above, but each has several important features which allow operation at greater distances and at larger angles off of the vertical. The various sensor modifications are summarized below.

The sensor referred to as MOD 1 used a tungsten halogen bulb in a quartz envelope for illumination and a thermo-electrically cooled lead selenium (Pb Se) detector. The sensor performed well at 9.2 metres above the water surface and was able to perform at certain angles off of the vertical and during limited wave conditions.

The sensor MOD 2 was similar to MOD 1 but used refractive rather than reflective optics. The sensor was able to define oil slicks at an operating height of 15 metres and had the potential to work up to 93 metres. MOD 2 was capable of operation at slant angles of 45° with heavy wave action.

MOD 3 was similar to MOD 2 but used a pulsed Xenon flash for illumination. The unit was tested at a height of 28 metres and was shown to have the potential to work at heights of 93 metres at large tilt angles. Testing at 28 metres did not involve oil but only the measurement of background signal levels. It was reasoned that since the system concept of oil versus water had previously been established, the system would operate correctly as long as sufficient signal was present. Extrapolation of data obtained at lower operating altitudes indicated that operation at 93 metres should be possible. MOD 3 was stated to have a scanning capability of ± 28° from

the vertical at a height of 45 m or ± 35° at 15 m.

A number of important points were brought up in the report concerning wave conditions and sensor orientations off of the vertical. The report stated that any wave will always present a facet which is normal to the view angle as long as the field of view of the sensor has a diameter of at least one-half the distance from peak to peak of the largest waves, assuming the angle of the sensor from the vertical is not excessive. Even under conditions where no specular reflection of light to the receiver optics occurs, there will be a diffusely reflected component but at a much lower power level. The absolute reflectance at a fixed wavelength varies strongly with aspect ratio, but, the ratio of reflectivity coefficients for the two measured wavelengths is essentially independent of aspect. Therefore, by using diffusely reflected radiation, the system was capable of correct operation even though the absolute return at each wavelength will be several orders of magnitude less than if the signal had been specularly reflected.

Several recommendations were made concerning other modifications which could be made to further improve instrument sensitivity and reliability. Modifications included using an open cycle Joule-Thompson cooler, In Sd detectors and the use of a laser operating at wavelengths of 3.4 and 3.9 um for illumination.

The potential of the sensor for remote unmanned operation is not known at the present time. The system as tested was only a prototype and as such, required considerable attention and adjustment. Since operation at the higher elevations did not involve oil on the water surface, and independent testing was not undertaken, definitive conclusions concerning the capabilities of these instruments cannot be made.

2.2 Oil Detection and Thickness Measurement by Capacitance Measurement

A number of oil detection devices have been designed that utilize the 40:1 dielectric constant mismatch between oil and water. The monitors consist of a capacitor whose upper capacitor plate floats on the oil-air interface while the lower capacitor plate is located in clean water below the slick. Since the dielectric constants of oil and water are 2 and 80 respectively, the total capacitance between the plates is inversely proportional to the oil layer thickness.

2.2.1 Oil Thickness Monitor

A floating oil thickness monitor as shown in Figure 2 has been used to measure oil film thicknesses in the bilges of ships. The floating capacitor is connected to a gauge which displays oil slick thickness. The device is said to be effective for slicks ranging from 0.5 to 6.4 cm thick with an accuracy of ±.3 cm (Klemas et al., 1971). It is unaffected by water purity, emulsified sludge, wax or froth but is ineffective in turbulent water or when oil thicknesses are less than .3 cm.

2.2.2 Brill Oil Spill Sentry

Oil Skimmers Inc. have marketed an oil skimmer with the capability of oil detection. The skimmer uses a plastic loop which floats on the surface of the water. Oil adheres to the loop as it is drawn through the water. The oil is scrapped off the loop into a reservoir where a capacitance probe measures the volume of oil. Compressed air is used to clear the reservoir at the end of each two minute cycle.

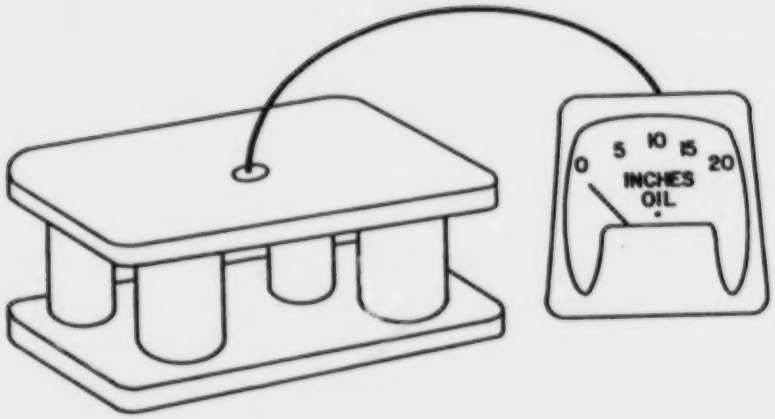


Figure 2. Oil Layer Thickness Monitor (from Klemas et al., 1971)

2.3 Modified Laboratory Techniques

A wide range of analytical techniques exist for measuring oil in the laboratory but the most adaptable ones appear to be those based on UV fluorescence and infrared absorption. Commercial instrumentation is available but the adaption of this equipment for offshore monitoring requires further consideration. Nevertheless, these techniques will be briefly reviewed and some of the commercially available units discussed.

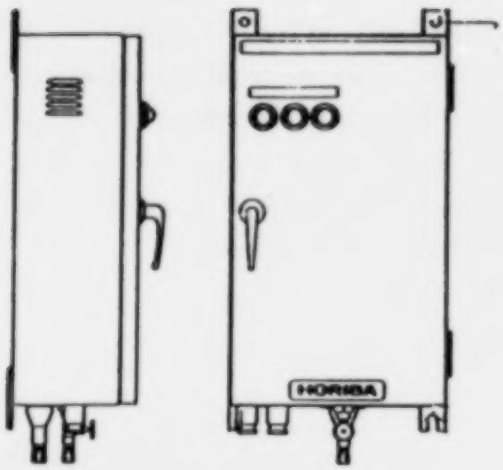
2.3.1 Infrared Absorbance

Horiba Instruments Inc. markets several oil content monitors that work on the principle of solvent extraction followed by non-dispersive infrared absorption. The model OCMA34 as shown in Figure 3 is used primarly in plant and shipboard application. It provides a continuous measurement and is designed to run unattended for long periods of time.

A portable unit is shown in Figure 4. Sampling is not automatic.

2.3.2 Ultraviolet Fluorescence

The Turner Designs Fluorometer as shown in Figure 5 is an example of a filter based UV fluorometer designed for laboratory and field use. The fluorometer features a quartz flow-through cell and automatic self ranging. As normally configured the instrument is extremely sensitive but a serious problem may be self-quenching of the fluorescent response; above quite low concentrations of oil (approx. 20 ppm) quenching becomes important and above a given concentration response gradually falls with increasing oil concentration to a negligible response above 1000 ppm. The flow-through cell is also highly susceptible to slick contamination.



SPECIFICATIONS

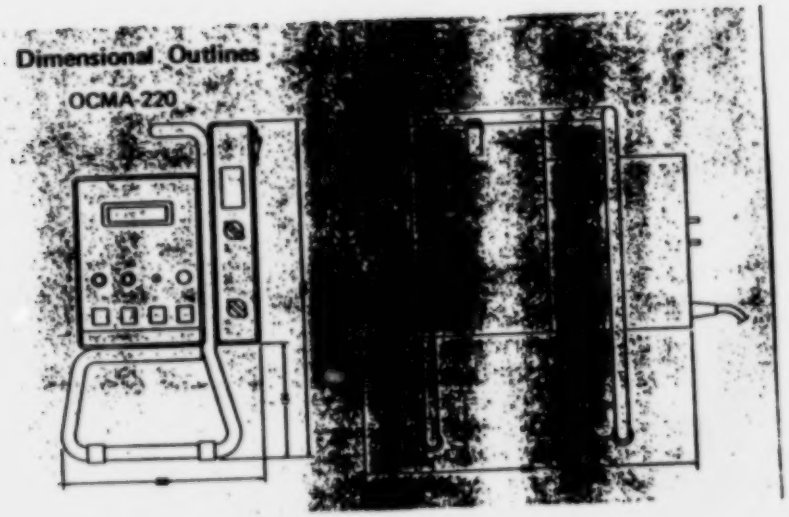
Applicable Standard:
IMCO '77 Resolution A.393(X)
Object of Measurement:
Oil content alarm
Principle of Measurement:
Solvent-extraction, non-dispersive infrared absorptiometry
Method of Measurement:
15 ppm oil concentration alarm
Response Time:
63% response within 20 seconds
Repeatability:
Within ± 1 ppm at 15 ppm

Drift:
Within ± 1 ppm/8 hr./ ± 5°C of ambient temperature change
Ambient Temperature:
0-50°C

Solvent:
Fluorochlorocarbon (Spec. Grv. 1.7 at 25°C.) approx. 600m*l* (= 1kg.)
Sample Requirement:
(1) Water Temperature: 2-35°C at sample inlet
(2) Flow Rate: 50-100*l*/hour
Plumbing:
(1) Sample Inlet: ¼" NPT
(2) Sample Outlet: ½" NPT

Solvent Flow Rate:
30m*l*/min.
Power:
100V/110V/115V/220V/230V/240V AC, to be specified by customer ± 10%.
Either 50Hz or 60Hz must be specified ± 5%
Power consumption:
Approx. 60VA
Alarm:
Alarms are given when oil concentration exceeds 15ppm and when the operation of the monitor is faulty

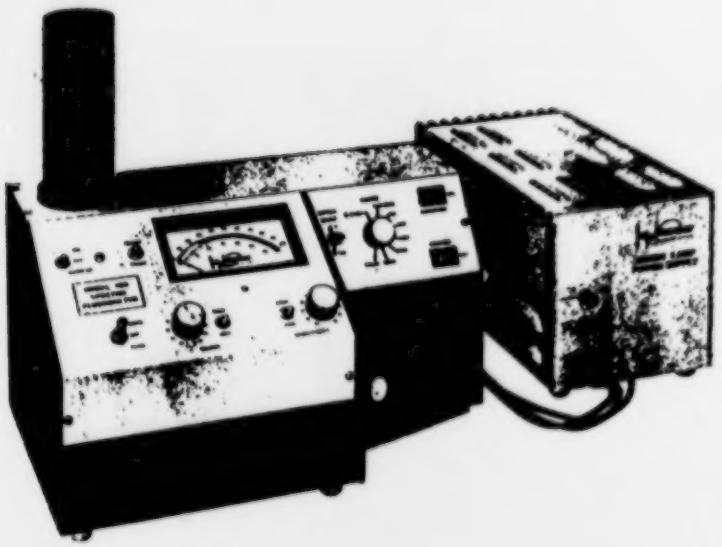
Figure 3. Horiba Instruments Inc. Model OCMA 34 Oil Content Monitor



SPECIFICATIONS

Principle:
Solvent extraction, NDIR analysis
Ranges:
0~5, 0~20 ppm or 0~50, 0~200 ppm
Measuring Object:
Organic hydrocarbon contamination in fresh or salt water sample
Repeatability:
0~20 ppm: ±2% of full scale
0~5 ppm: ±4% of full scale
0~200 ppm: ±2% of full scale
0~50 ppm: ±2% of full scale
Calibration:
Known oil/solvent mixture for span calibration; pure solvent for zero
Sample Volume:
0~20 ppm: 15mℓ, 0~5 ppm: 20mℓ
0~200 ppm: 5mℓ, 0~50 ppm: 15mℓ
Solvent: Fluorochlorocarbon
Solvent Volume:
0~20 ppm: 15 mℓ, 0~5 ppm: 10 mℓ
0~200 ppm: 20 mℓ, 0~50 ppm:15 mℓ
Extraction: By built-in extractor
* Externally extracted samples may also be measured.
Ambient Temperature: 0 ~ 40°C
Output: 0 ~ 100 mV DC
Power Requirement: AC Line, 50 or 60 Hz, Approx. 50 VA
Dimensions:
220(W) x 362(D) x 375(H) mm
[8.7(W) x 14.3(D) x 14.8(H) inch]
Weight: Approx. 10 kg (22 lb)

Figure 4. Horiba Instrument Inc. Model OCMA-220 Oil Content Monitor



SPECIFICATIONS

Sensitivity: 5 parts per trillion
Wavelength range: excitation, 200 to 1000 nm
emission, 300 to 700 nm
Range selector: precision ranges of 1, 3, 10, 30, 100, 300, 1000 ±1%; high-low switch of approximately 30:1 continuous control covering over 4:1
Bandwidth: excitation, 15 nm; emission 15 and 60 nm
Photometric meter accuracy: ±1%
Electrical output: 0-1 volt
Sample: accepts 10 x 10 (I.D.) x 45 to 75 nm high square cuvettes, or 12 x 75 nm round cuvettes. Minimum sample volume is 2.2 mL in the square cuvette and 1.8 mL in the round cuvette
Power: 105 to 130 volts, 48 to 65 Hz, 340 watts
Dimensions: electro-optical unit, 533 mm W x 298 mm D x 279 mm H exclusive of lamp chimney; weight 20 kg. Xenon lamp power supply 222 mm W x 406 mm D x 235 mm H, weight 14.5 kg.

Figure 5. Turner Designs Fluorometer

2.4 Floating Reflectometer

Oil floating on a water surface may be detected by reflectance measurement since the two liquids possess different refractive indices. Oil (n=1.40) will appear brighter than water (n=1.33) and may appear much brighter if multiple internal reflection occurs within the oil. Two prototypes and a manufactured unit will be discussed here.

The first prototype relied on surface waves and currents to move any surface film through an S-shaped baffle. The baffle network was used to calm the water surface and reduce ambient light levels. This first prototype was found to be sensitive to water surface conditions so a second prototype was constructed which provided a more robust buoyancy system, a longer baffle and an impeller to draw the liquids through the baffle. The angle of incidence of light onto the water surface was also changed from 16° to 10° to accommodate the deep baffle and further minimize the sensitivity to water level changes (Goolsby, 1971)

Hallikainen Inc. built a commercial unit which was quite similar to the second prototype. The unit as seen in Figure 6 was said to be rugged, and simple to operate but could be confused by floating substances other than oil (Klemas, 1971).

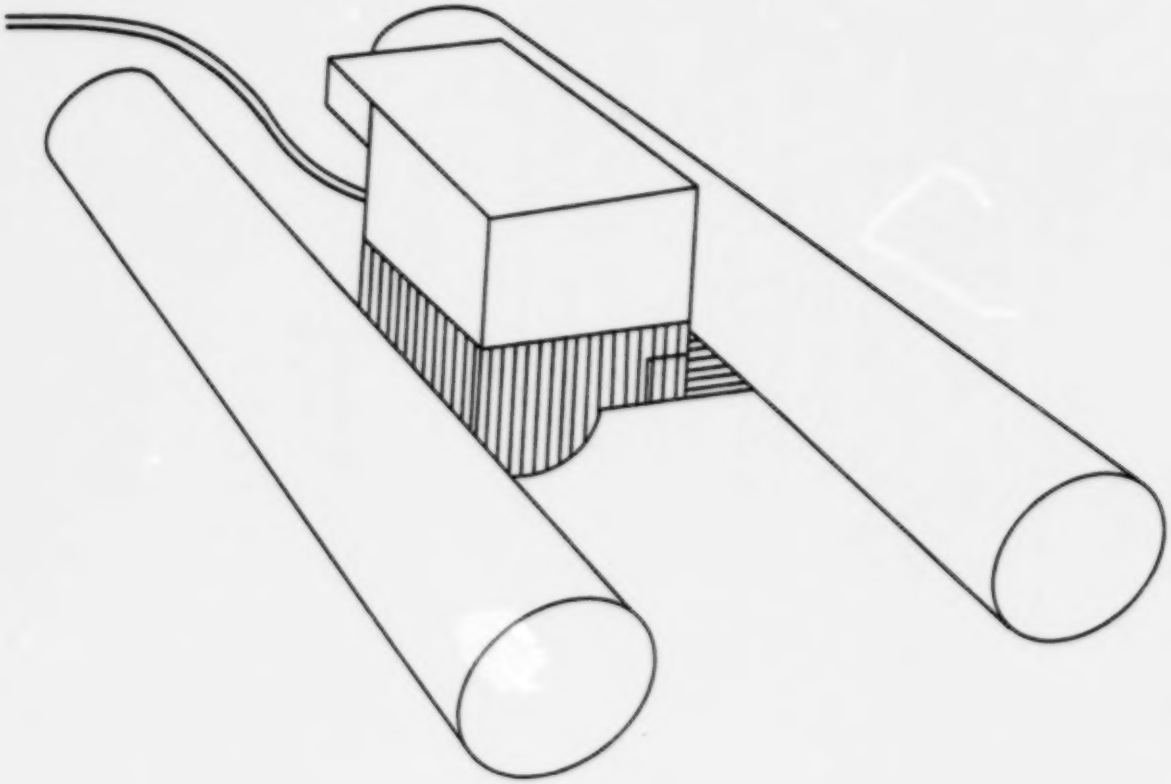


Figure 6. Floating Reflectometer manufactured by Hallikainen Inc.

2.5 Vapour Detectors

Goodson et al. (1975) has documented seven different sensors that are capable of detecting hydrocarbon vapours. They are:

1) experimental thin film resistors
2) hot wire and catalytic hot wire commercial sensors
3) PNP transistors
4) radioactive ionization sensor
5) Taguchi semiconductor gas sensor (TGS)
6) Esso piezoelectric oil-on-water sensor
7) Wesmar WSM-350.

The Taguchi Gas Sensor (see Figure 7) was found to have the best features which included reliable operation over a large range of temperatures, humidity and salt spray conditions.

The Taguchi Gas Sensor is a small semi-conductor chip whose conductivity increases when certain organic vapours are absorbed onto its surface. A resistance heater is incorporated into the sensor which reduces sensitivity to water vapour and speeds the reversal of the absorption process. The cycling time for the sensor is one to five seconds. The sensors are sensitive to hydrocarbon vapours at levels as low as 5-25 ppm and are able to retain this sensitivity for at least 6 months of continuous operation. Their low cost (typically less than $10.00) and low power requirements (0.4 watts) makes them ideal for a buoy mounted configuration. The sensor itself can act as a relay so that an alarm relay is not required.

The Taguchi Gas Sensor has been deployed both in a self-contained buoy configuration (see Figure 8) and in a dockside configuration. During the dockside configuration, the buoy was found to be sensitive to carbon monoxide vapours emitted from engines, as well as hydrocarbon vapours. To compensate for this, two Taguchi Gas Sensors were deployed, with one filter to remove hydrocarbon vapours. Since this sensor only detected carbon monoxide, by subtracting its output from the other sensor's output, the system could be made to alarm only in the presence of hydrocarbon vapours.

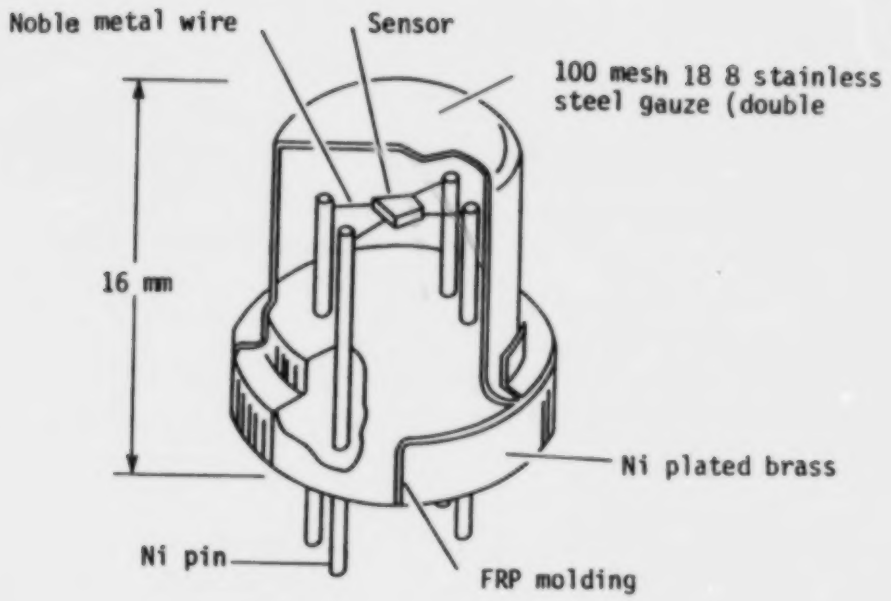


Figure 7. Taguchi Gas Sensor (from Flanagan et al., 1976)

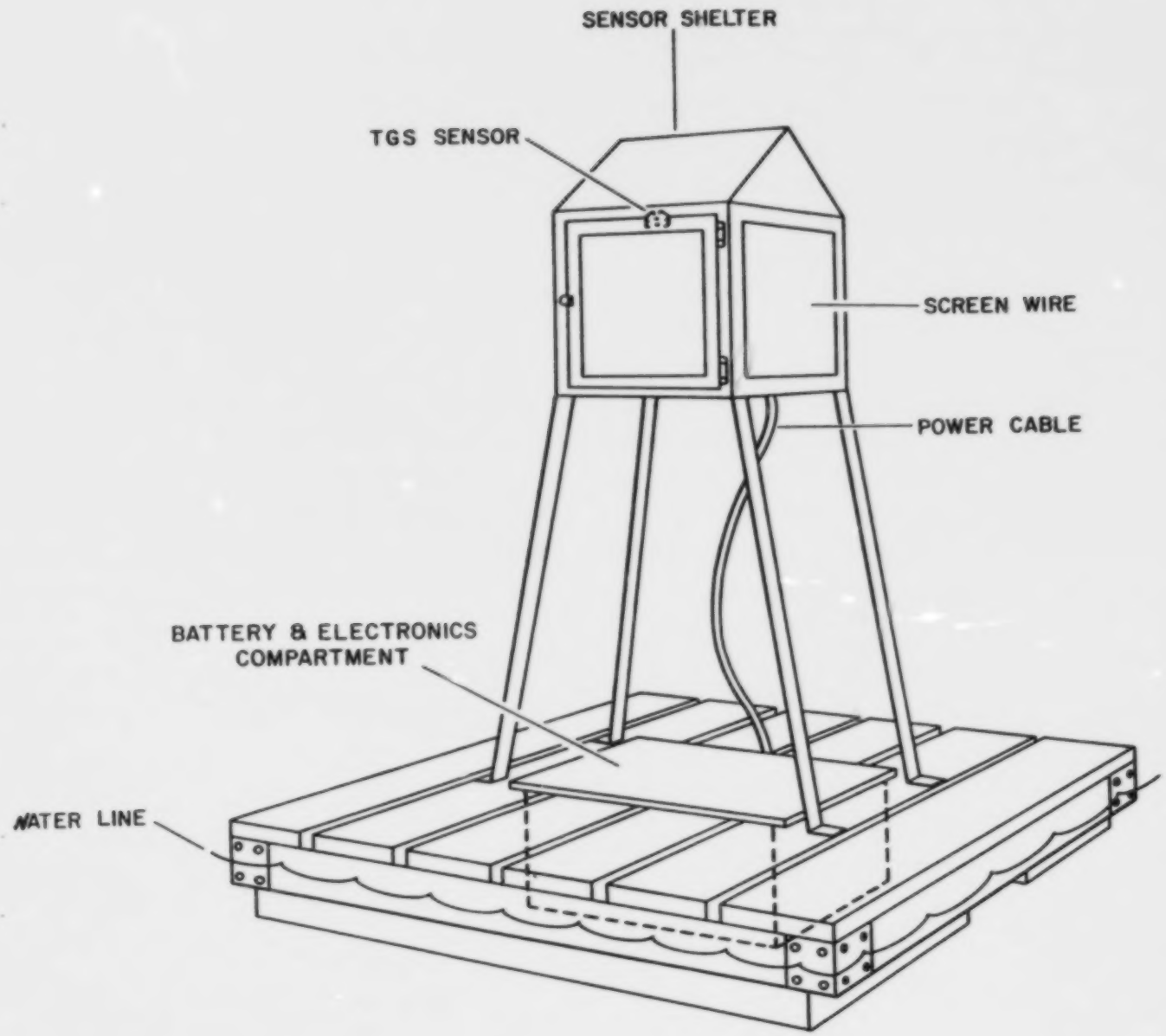


Figure 8. Oil Pollution Detection Buoy Utilizing Taguchi Gas Sensor (from Goodson et al., 1976).

The system was said to be quite reliable and produced a positive response at all times when a spill occurred. The sensor was able to produce a response in a few seconds to oil spills as small as 25 mL which occurred upwind. The device was not responsive to heavy oils with small volatile components such as No. 6 fuel oil and lubricating oil (Goodson et al., 1976).

The Midwest Research Institute has designed an updated oil vapour monitoring system utilizing two Figaro 812 gas sensors (W. Leslie, pers. comm.). Like the Taguchi gas sensor, the Figaro sensor may also be confused by other contaminants so a two sensor system is again required.

The system, as shown in Figures 9 and 10, uses an air pump and charcoal filter to remove hydrocarbon vapours from the air stream entering the second sensor. The system has an average power consumption of 0.2 watts which permits remote deployment utilizing a solar panel and rechargeable battery. Although field deployment of this sytem has not been undertaken, it is anticipated that the sensor would require testing and recalibration at six month intervals. The sensors have the ability to survive severe weather conditions, including dust and salt spray, and are expected to last several years during normal operations.

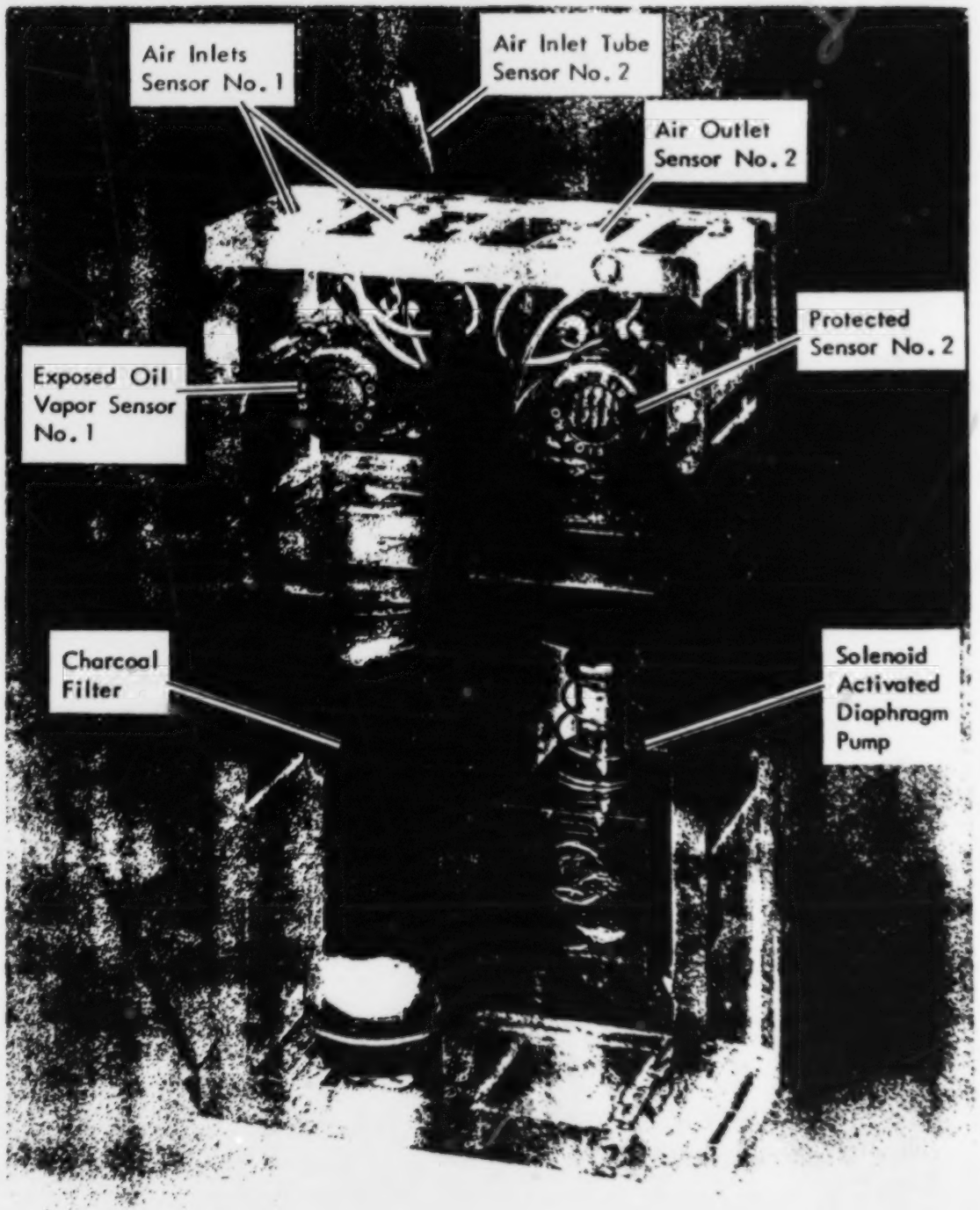


Figure 9. Photograph of OVS-2 Components (excluding printed circuit boards) located within the protective enclosure (from Midwest Research Institute, Kansas City, Missouri).

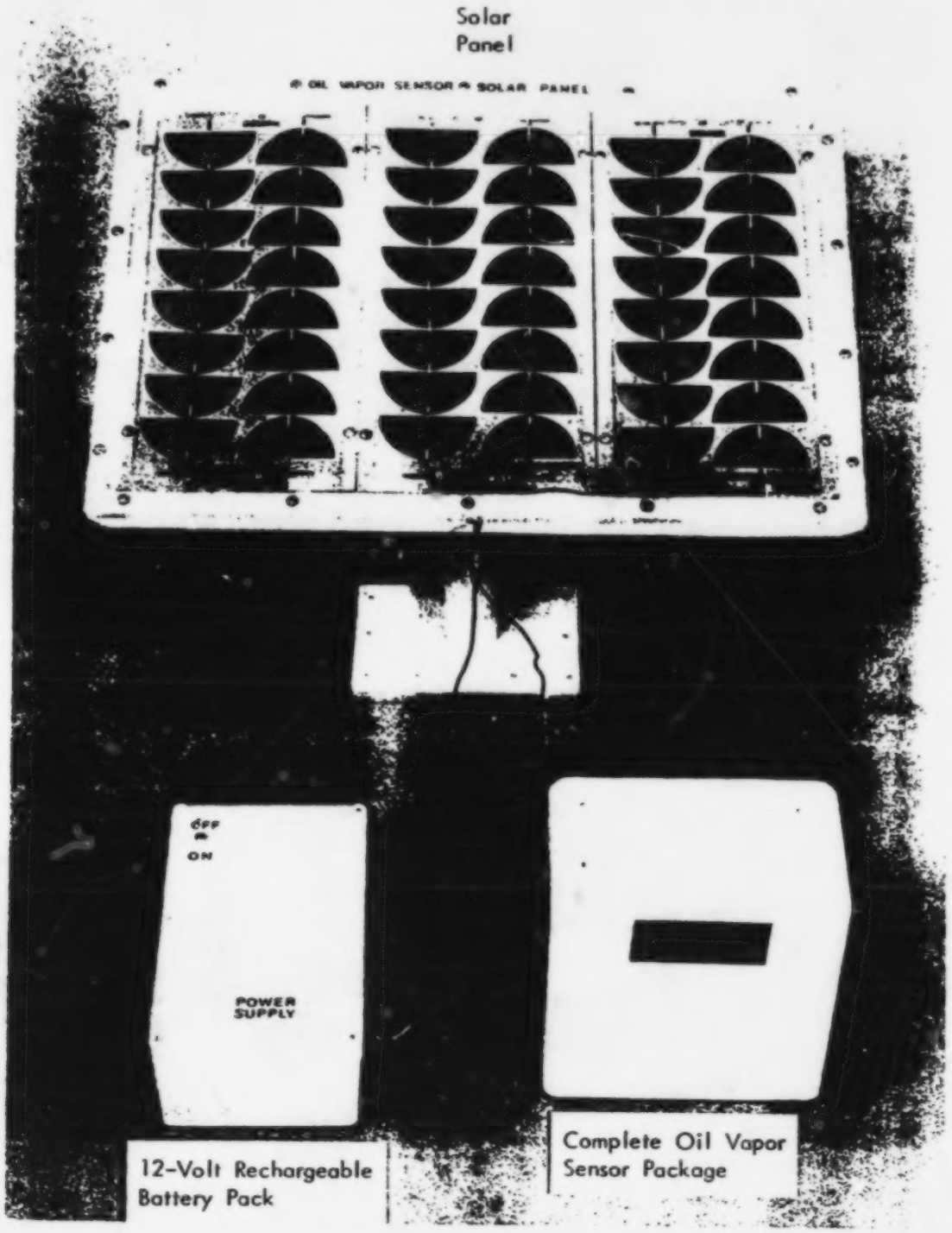


Figure 10. Complete Oil Vapour Sensor Unit with Solar Panel and Rechargeable Battery Pack (from Midwest Research Institute, Kansas City, Missouri).

2.6 Differential Evaporation

Horvath et al. (1974) have designed a floating oil slick sensor which utilizes the differential in evaporative cooling rates between oil and water. The device, as shown in Figure 11, uses 3 thermistors. One thermistor (To) is exposed to oil films at the water surface, while the second thermistor (Tw) is passed through a well tube and exposed to uncontaminated water below the surface. Both these thermistors are then withdrawn and allowed to cool momentarily at ambient air temperature and humidity. A third thermistor measures ambient air temperature (Ta). A decision whether an oil slick is present is then based on the Evaporation Response Ratio (ERR), where:

$$ERR = \frac{Ta - To}{Ta - Tw.}$$

This procedure was found to cancel most environmental affects.

A probe cleaning system is required to remove any oil contamination or biological accumulation from the thermistors. Solvent and compressed air are stored onboard and used for this purpose. Total weight of the package is 186 kg, which includes a 12 volt automotive type battery, 32 litres of tricloroethylene solvent and 1.7 kg of compressed air (2,000 litres at one atmosphere). One complete cycle of probe insertion, withdrawal, temperature measurement and cleaning requires approximately 105 seconds. At continuous duty, there is sufficient onboard power, solvent and compressed air for one week of operation. If the duty cycle is reduced, this can be extended to several months. No reference was made to minimum detectable slick thickness or performance in a variety of oil types.

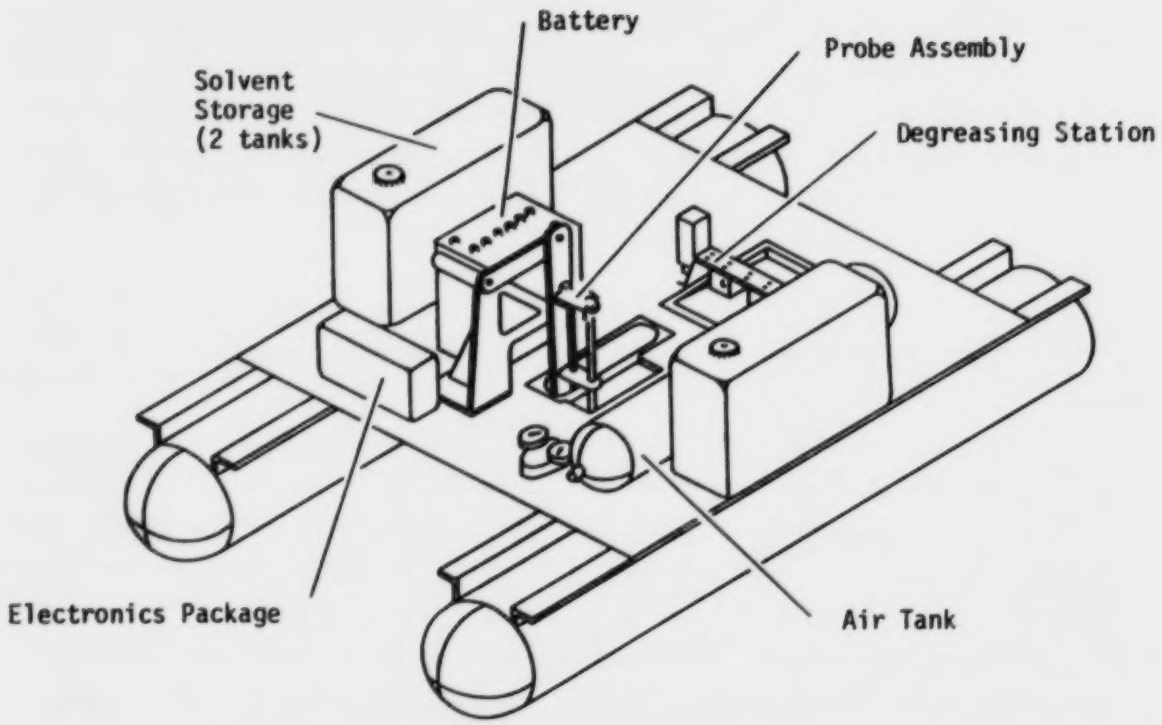


Figure 11. Layout of Differential Evaporation Oil Detector

2.7 Permeable Membrane

Durham Associates (Zahkra, 1974) have designed an oil spill detection system which incorporates a unique selectively transmissive membrane which retains water but allows oil to flow through it. The buoy sensor is constructed so the membrane is floated at the air-water interface. Any oil that is present on the water surface will contact the membrane and flow through to a small receptacle where the presence of oil is detected by a float switch. The signal is then transmitted to a monitor consol by underwater cable. The obvious drawback to the system is an ability to only alarm once after which time the buoy sensor must be disassembled and cleaned. Occasional replacement of the permeable membrane is also required.

2.8 Viscometer

Another type of *in situ* oil detection device has been designed which operates like a viscometer (Kriebel, 1973). An electrical motor drives a spinning cylinder which is enclosed in a slightly larger cylindrical shroud. The device is partially submerged so that under normal operational conditions lubrication between the spinner and shroud is provided by water. In the presence of an oil slick, the spinning cylinder becomes coated with oil so that greater current is required by the electrical motor to maintain a constant speed. By monitoring the motor current, the presence or absence of oil can be detected.

Figure 12 shows the basic configuration of the device. Test data indicates that most oil slicks are detected in the absence of waves, and there is limited capability to discriminate the type and thickness of oil slicks. Self-cleansing of the spinner following the slick occurred with most oil types. The sensor was found to be sensitive to water level variations due to waves and tides, as well as to clogging from floating debris. Expected performance under large wave conditions was not expected to be favourable. Recommendations were made for a similar device in which an inverted cup containing the spinner would drop through the water surface and slick. Once submerged, the cup would contain a quiescent trapped air bubble and a section of the oil slick, on which the evaluation could be undertaken. The authors believed this type of device had the ability to operate in wavey conditions.

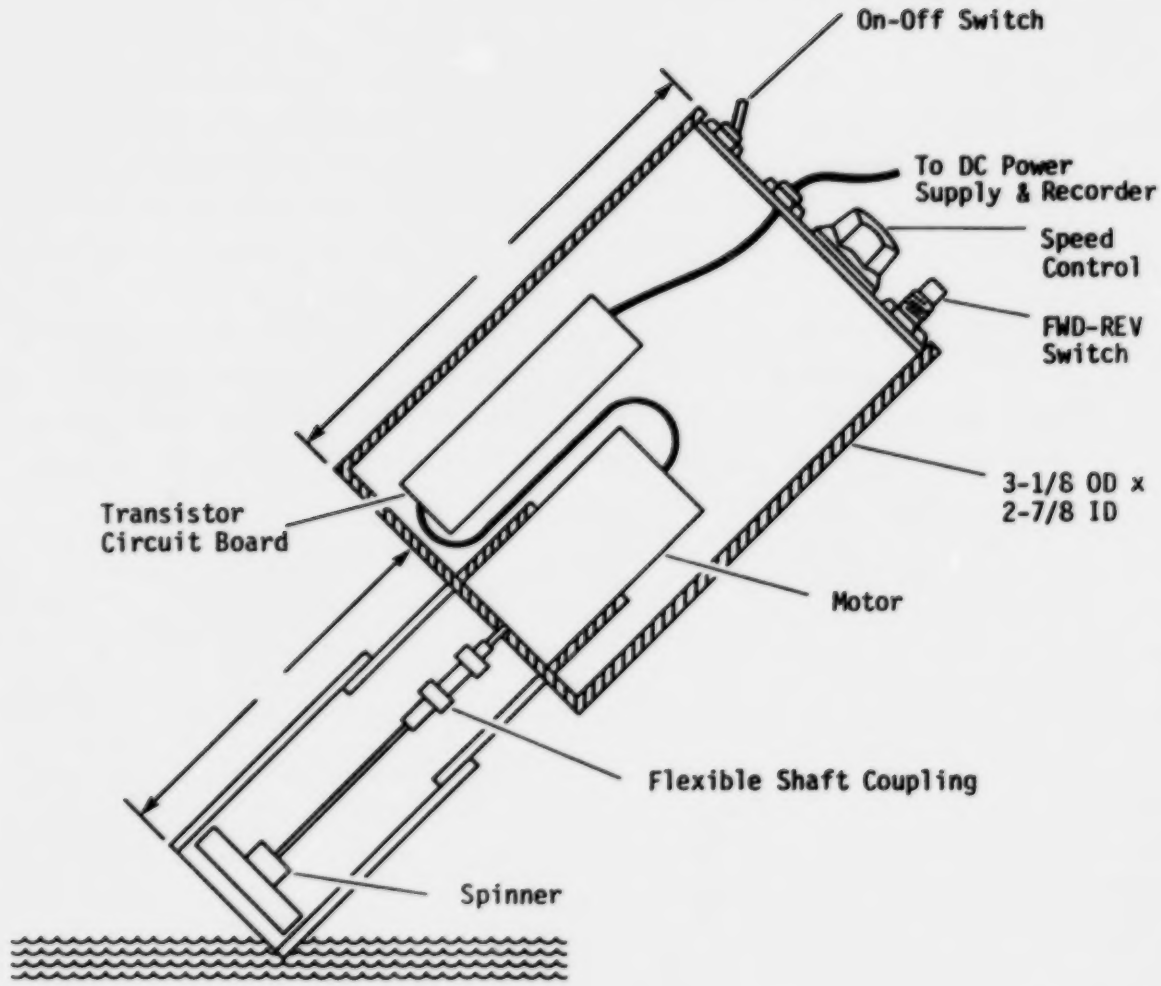


Figure 12. Viscometer Oil Detection Device (from Kriebel, 1973)

2.9 Bennett Pollution Controls

Bennett Pollution Controls has designed an oil detection buoy which utilizes a loop of oleophilic material glued together with an oil soluble but water insoluble glue. The glue is located at the water line and dissolves within several minutes when exposed to light oils through to diesel fuels. The device will not respond to heavy oils such as Bunker-C.

When the glue is dissolved, the buoy transmits a radio signal back to the shorebase where an alarm is sounded. Drawbacks to the system are that the buoy batteries and glued loops periodically have to be serviced. Servicing of the buoy is also required after each alarm.

2.10 Oil Film Sampler

The requirement to measure ambient oil concentrations in rivers and harbours led to the development of a continuous flow *in situ* oil film collector. Investigations to construct a feasible unit were undertaken by Schatzburg et al. (1972), who identified an effective sorbant for oil collection. LeVantin et al. (1974) constructed the wier type oil skimmer with pump and flow measurement device.

Design of the oil filter cartridge was quite successful. It consisted of a cartridge 30 cm in diameter and 6.3 cm thick filled with open cell polyurethane foam. The foam showed a 90% collection efficiency and permitted easy extraction with carbon tetrachloride, a solvent commonly used in the infrared absorption method of determining oil concentration.

The weir approach to oil collection, as shown in Figure 13, was not as successful. The bobbing action of the skimmer in waves caused a pumping action around the skimmer which repelled oil films, resulting in a serious reduction in the amount of oil collected. It was recommended that the weir type of oil collection in an open environment be discarded.

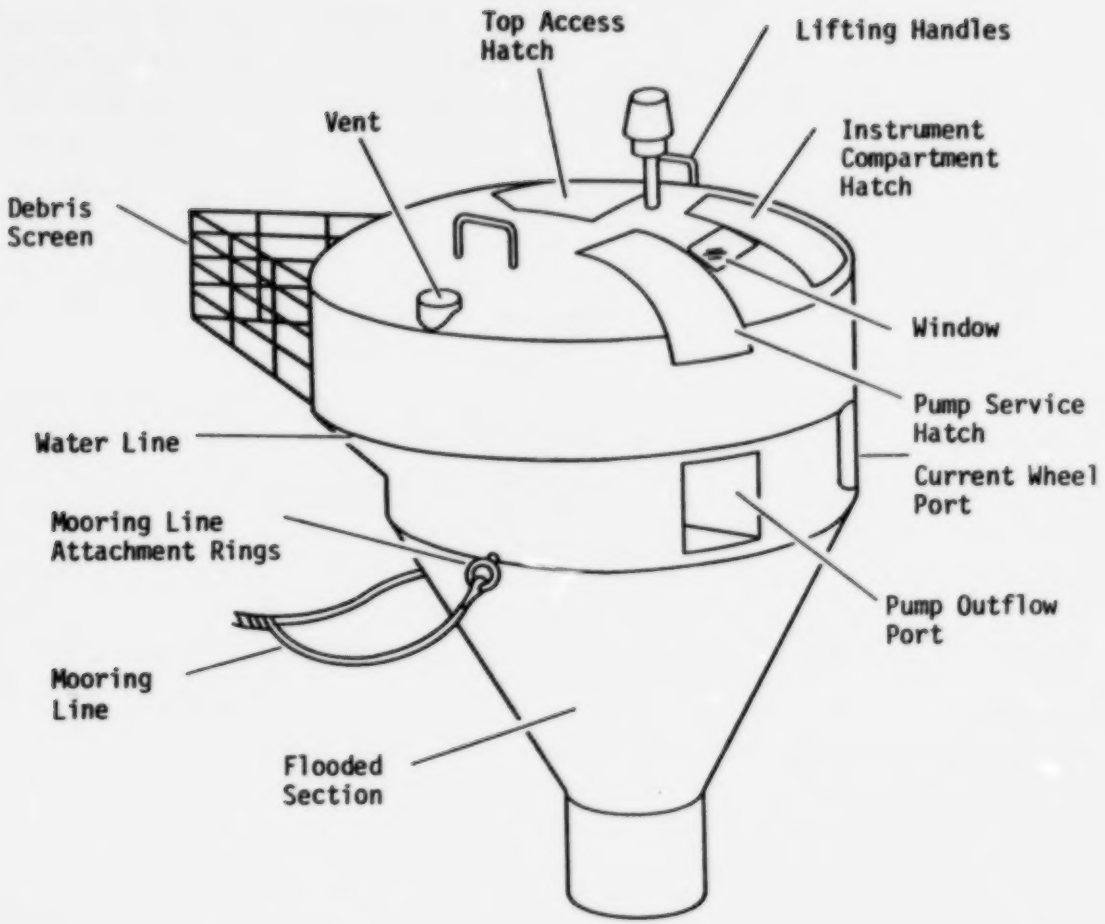


Figure 13. Oil Film Sampling Buoy (from LeVantin et al., 1974)

2.11 LIDAR Polarimeter

Backscatter depolarization of coherent light is a remote sensing technique which has been used in oil-on-water detection. The system designed by Rouse et al. (1974) was a dual laser system and utilized the fact that oils act as lossy dielectrics at visible wavelengths. During conditions of turbid water, which is the usual condition in an open water situation, both polarizations are attenuated radically but equally when an oil slick is present. Clean turbid water results in significant differences between horizontal and vertical components of the backscattered signals. By employing two frequencies of excitation and detection, identification of oil type is possible. Oil slick thickness would also be calculated knowing the amount of attenuation.

The Dichromatic LIDAR Polarimeter as shown in Figure 14 utilized a red helium-neon laser and a blue helium-cadmium laser. The device was designed primarily as an experimentation tool and as such had more capabilities than would be required in a single monitoring situation. The device proved to be a very reliable oil detection device and was operated for over a year in lab and field situations. It was used in a scanning mode and detected oil films day or night at ranges up to 100 metres away. The system had a low false alarm rate, ignored floating debris and operated well in wavey conditions. Recommendations were made for a less expensive single red laser unit which would still have day/night capability and azimuth scanning.

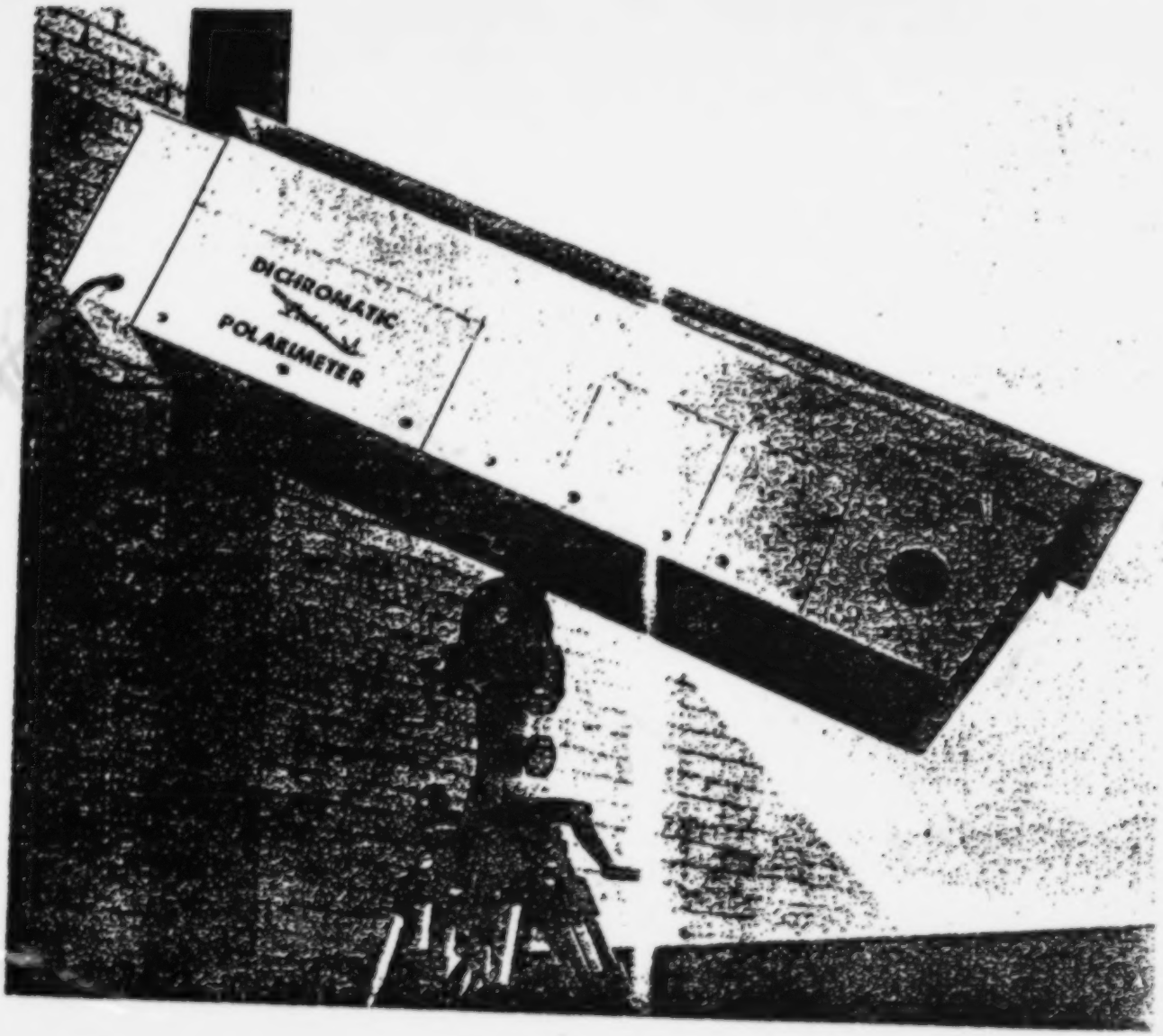


Figure 14. Dichromatic Lidar Polarimeter (from Flanagan et al., 1976)

2.12 Fluorescence Techniques

Fluorescence is the process by which a target molecule absorbs a photon and then emits a different photon of longer wavelength at some later time. A number of instruments have been designed which detect the presence of oil due to its characteristic fluorescence. Most techniques irradiate the oil with short wavelength light and then measure the oil fluorescence in the visible region. The external conversion ratio is usually low so that high powered irradiating sources are required if operation is undertaken at long range.

2.12.1 Petroleum Oil Detection Buoy System

The Spectrogram Corporation of North Haven, Connecticut has designed a floating oil detection buoy utilizing the oil fluorescence technique. The buoy contains a 12 volt battery and carries all detection and alarm circuity onboard. The unit requires a cable to shore to signal the alarm although this could have been handled be telemetry.

The electro-optical system is mounted inside the main base frame from which three legs extend radially outward and suspend the main housing over the water (see Figure 15). The excitation lamp is a 40 watt low pressure mercury vapour lamp but it is modulated which results in a total power requirement for the buoy of approximately 0.6 watts.

The optical head employs three silicon detectors. One detector is used to monitor lamp intensity while another measures reflectance at the .365 um mercury line. The third is situated behind a .340 um mid-UV bandpass filter and measures oil fluorescence. Both the excitation source and collection optics operate through a quartz window located 45 cm above the water surface. A sun shield is used to minimize background radiation levels.

The output signals from the reflectance and fluorescence channels are fed through a differential amplifier whose output signal is proportional to the fluorescence signal minus the reflectance signal. This circuitry

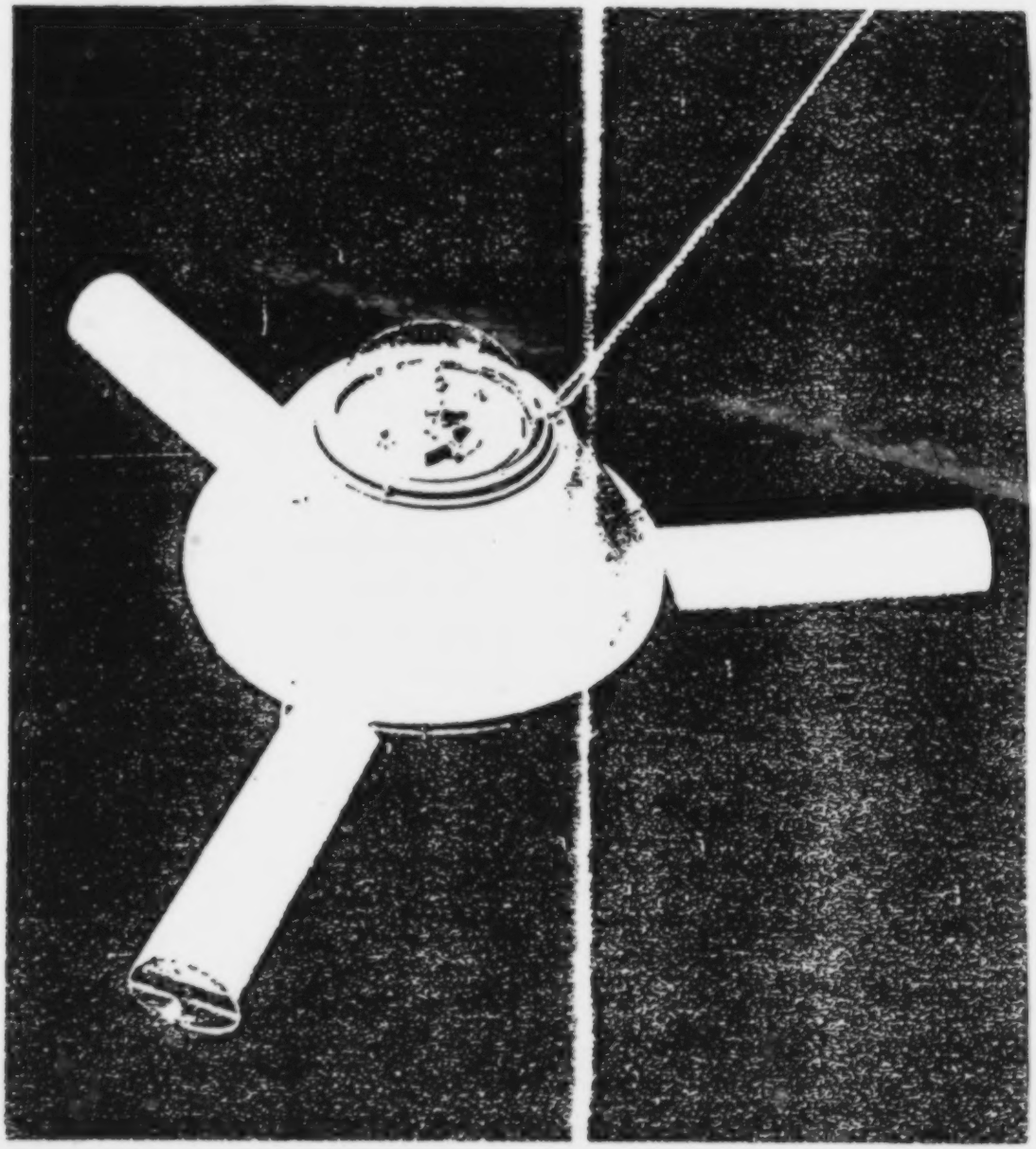


Figure 15. Spectrogram Corporation Petroleum Detection Buoy (from Flanagan et al., 1976)

is said to compensate for floating debris and surface conditions not related to petroleum products. The output from the differential amplifier serves to activate the alarm if oil is present.

The buoy has a removable dome under which are gain controls for the reflectance and fluorescence channels, and an alarm threshold adjustment. Adjustment of these controls is required for each particular deployment. The buoy has been deployed six times, over which time it has proven to be an effective oil detection device (pers. comm. Herb Graham).

2.12.2 Scanning Oil Spill Detector

Baird-Atomic of Bedford, Massachusetts has constructed a Scanning Oil Spill (SOS) Detector. The device measures oil fluorescence in two spectral regions after excitation with a xenon flash. The device has good range abilities at night but very restricted abilities during daylight hours.

Specifications for the Scanning Oil Spill Detector are given in Tables 1 and 2. An overall view of the detector is given in Figure 16. The system uses a focused xenon lamp flashing at a rate of 15 Hz to induce oil fluorescence. The spectral regions 0.3 to 0.4 um and 0.4 to 0.55 um are then sensed (Eldering et al., 1975). Seawater fluoresces the same amount in both regions whereas most oils fluoresce primarily in the shorter wavelength region, with the exception of heavy oil which tends to fluoresce primarily at longer wavelengths.

Through a fairly sophisticated computer system an oil-no-oil decision is made. A device for measuring the presence of fog is included in the system which is capable of limiting the false alarm rate during conditions of reduced visibility. The device was primarily a research tool and as such, had numerous capabilities not required in simple monitoring situations.

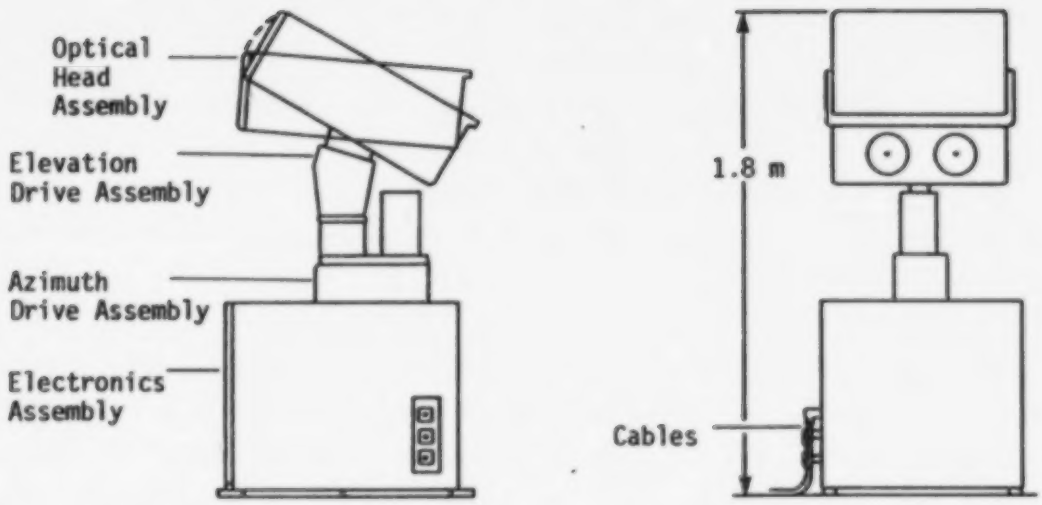


Figure 16. Scanning Oil Spill Detector (from Eldering et al., 1974)

TABLE 1

**SCANNING OIL SPILL DETECTOR,
PRELIMINARY OPERATING SPECIFICATIONS**

(from Eldering et al., 1974)

Range	600 feet maximum, less in fog
Hours of operation	45 minutes after sunset to 45 minutes before sunrise
Elevation scan	6 to 30 degrees below horizon (adjustable) at 0.5 degree per second
Azimuth scan	±165 degrees (adjustable) at 2.5 degrees per second
Scan pattern	Programmable
Alarm criteria	Detection on two consecutive scans
Beam size	0.5 degree elevation by 2.5 degrees azimuth (projects to maximum of 50 by 25 feet on sea surface at 600 feet and 6 degrees below the horizon)
Minimum spill size	75 percent of beam area
Minimum spill thickness	1 micron (at maximum range)
Display	Remote via rf or wire
Alarm indicators	Power on Equipment active Equipment failure Oil alarm Oil type (light/heavy) Position
Head	22" W by 22" D by 9-1/2" H, 95 pounds
Base	24" W by 28" D by 24" H, 225 pounds
Drive	40 pounds azimuth, 40 pounds elevation
Power	110 Vac, 60 Hz, 1,600 watts
Operating temperature	-15 to 120°F
Environment	Waterproof, oilproof, dustproof, explosion proof (internally pressurized with dry inert nitrogen, pressure switch power interlock)
Lamp life	6 months (12 hours per night) (less than 1 hour replacement time)
Mean time between failures	900 hours
Mean time to isolate and repair	Less than 3 hours

TABLE 2

SCANNING OIL SPILL DETECTOR, TECHNICAL PARAMETERS
(from Eldering et al., 1974)

	EXCITATION
Source	Xenon flash lamp
Arc size	2 inches by 5 millimeters
Voltage	850 volts
Input Energy	6.5 joules per flash
Duration	10 microseconds
Synchronization	60-Hz power line
Rate	15 flashes per second
Trigger	External
Average power	98 watts
Cooling	Forced air
Filter	Reflection type
Spectral bandpass	225 to 275 nanometers
Lens	6" diameter, 12" focal length, quartz
	FLUORESCENCE
Lens	6" diameter, 12" focal length, quartz
Beam splitter	Half-silvered quartz
Filters	Glass transmission
Spectral bandpass	300 to 400 nanometers and 400 to 550 nanometers
Detectors	Photomultipliers, IP28 and EMI 9785B
Voltage	1,100-volt maximum
	SIGNAL PROCESSING
Frequency bandpass	600 Hz to 60 kHz
Pulse Measurement	Synchronized dump, integrate and hold for two fluorescence detectors, flash monitor and fog monitor
Computer	Prototype: PDP-11/05; production: LSI-11
Detection criteria	Ratio must exceed noise level when averaged over eight pulses
Alarm contacts	0.3 milliampere at 12 volts
Alarm reset	Automatic if no detection during next scan

2.12.3 Laser Fluorosensor

Numerous laser fluorosensor systems have been designed to detect oil spills in the offshore environment. Most of these systems are designed to be mounted on aircraft and used as experimental instruments. Although at present there is not a suitable laser fluorosensing system for sentinel monitoring, this method will be considered since it offers a number of advantages over other techniques.

Laser fluorosensors are somewhat unique in that they can detect both oil-in-ice and oil contained within the water column. If the fluorosensor incorporates detection in a number of spectral channels, identification of oil type is also possible. Some laser fluorosensor systems are also capable of determining oil film thickness.

State-of-the-art laser fluorosensors for oil slick detection generally use a pulsed laser to induce fluorescence in the target. The target fluorescence is then measured in a number of spectral regions and the target is classified by recognition of its characteristic fluorescence signal. Components of the laser fluorosensor system include the laser transmitter, telescope and receiver, a spectrometer and a data acquisition and display device.

The Mk III laser fluorosensor built for the Canada Centre for Remote Sensing is an example of a state-of-the-art system. The system's specifications are given in Table 3. The system uses a pulsed nitrogen laser operating at a pulse rate of 100 Hz with an energy of 1 mJ/pulse. A LIDAR altimeter is incorporated into the sytem which permits range gating of the detection system. Range gating permits sampling only during the period of fluorescent return. Combined with background subtraction, these techniques allow the sytem to operate in full daylight while detecting targets with relatively weak fluorescence signals.

The induced fluorescence is dispersed into sixteen spectral channels covering the range from 370 nm to 710 nm. Target classification is provided by correlating the fluorescence spectra with cataloged spectra from a number of different oil types. Total weight of Mark III Laser Fluorosensor including

TABLE 3
SPECIFICATION OF MK III LASER FLUOROSENSOR
(from O'Neil et al., 1980)

Laser Transmitter Characteristics

Laser Type	Nitrogen Gas Laser
Wave Length	337 nm
Pulse Length	3 - n sec FWHM
Pulse Energy	1 mJ/pulse
Beam Divergence	3 mrad x 1 mrad
Repetition Rate	100 Hz

Fluorosensor Receiver Characteristics

Telescope	f/3.1 Dall Kirkhan
Clear Aperture	0.0232 m^2
Intensive On-Gate Period	70 n sec
Nominal Spectral Range	386 - 690 nm
Nominal Spectral Bandpass	20 nm/channel
Lidar Altimeter Range	75 - 750 m
Lidar Altimeter Resolution	1.5 m

data processing package is 307 kg (Barringer, 1981).

A Mk IV system is currently being built which uses an excimer laser operating at a wavelength of 308 nm, a pulse rate of 150 Hz and a much higher energy of 35 mj per pulse. Total weight of this system is anticipated to be under 200 kg (Till et al., 1985).

Other laser fluorosensor systems include the Airborne Oceanographic LIDAR (AOL) described by Hoge et al. (1980). The AOL uses a nitrogen laser and incorporates forty spectral channels. Another laser fluorosensor system is described by Frank et al. (1983). Both these systems are large, expensive and require an experienced operator at all times.

Somewhat simpler systems which have been deployed from helecopters have been used for chlorophyll measurement and detection on minerals. Bristow et al. (1979) details a system used for measuring chlorophyll a concentrations down to 2 ug/L at operating elevations from 200 m to 400 m. Seigel et al. (1982) describes a laser fluorosensing system used for luminescent mineral exploration. The device has been used at ranges of approximately 30 to 60 metres.

Although the laser fluorosensor systems discussed have no application for monitoring from an offshore platform, the method of detection and the technology used may be relevant. Laser fluorsensing offers a number of advantages over other detection systems and deserves further consideration. Included in Appendix A is a brief outline of a system which may be suitable for short range monitoring from an offshore platform. Preliminary calculations indicate that such a system is possible, however, a more detailed evaluation is recommended before development of such a system.

2.13 Summary

A wide range of local area oil detection devices have been discussed. Most were designed for deployment in harbours and rivers and as such, have little potential for detecting oil slicks in an offshore environment. Table 4 summarizes the sensors in two categories; those with potential for offshore deployment, and those without potential. Brief comments are made concerning why each sensor received it particular rating. Of those sensors with potential for offshore deployment, a further breakdown is made.

The first four sensors listed included the Wright and Wright Infrared Oil Film Monitor, Modified Laboratory Techniques, Vapour Detectors and the Petroleum Oil Detection Buoy (Fluorescence). These four sensors can be considered points sensors. They will not detect oil under all conditions, but their costs are generally below $10,000 per unit.

The Wright and Wright Infrared Oil Film Monitor offers good potential and will be discussed in subsequent sections of this report. Analytical laboratory techniques have no application for monitoring oil on the water surface but are highly recommended for monitoring effluent streams being discharged from offshore platforms. Vapour detectors offer some potential but further evaluation will be required before any specific recommendations can be made. The Petroleum Oil Detection Buoy manufactured by Spectrogram Corporation received considerable testing and was found to be a reliable sensor. Deployment at an offshore rig could be difficult however, and the sensor could not be relied upon during conditions of large or breaking waves.

The remaining sensors that appear to offer potential include the Dichromatic LIDAR Polarimeter, Scanning Oil Spill Detector and Laser Fluorosensors. All three have good range capabilities, the ability or potential to scan and the potential for positive identification of the oil. They are generally complex and expensive since they incorporate microprocessors, optical systems and high intensity illumination sources. Further investigation of these techniques is recommended. Laser fluorosensing is considered in greater

TABLE 4

SENSOR SUMMARY

Unsuitable Devices	Comments
Rambie Oil on Water Sensor	- too sensitive to background and environmental conditions
Texas Instruments Active Sensor	- unproven in actual oil slick conditions
Capacitance Measure	- 0.5 cm minimum detectable slick thickness
Floating Reflectometer	- sensitive to waves, confused by foreign substances
Differential Evaporation	- mechanically and logistically difficult
Permeable Membrane	- membranes require periodic replacement and only signal once
Viscometer	- too sensitive to waves
Hydrocarbon Soluble Adhesives	- requires periodic replacement and can only signal once
Surface Film Sampler	- ineffective at retrieving sample

Sensors with Potential	Comments
Wright and Wright Infrared Oil Film Monitor	- the only off-the-shelf monitor available, proven design
Modified Laboratory Techniques	- could be used to monitor effluent streams
Vapour Detectors	- good potential with light end hydrocarbons
Petroleum Oil Detection Buoy	- good detection but deployment may be difficult
Dichomatic LIDAR Polarimeter	- good detection capabilities but expensive
Laser Fluorosensor	- good detection capabilities but expensive

detail in Appendix A.

Six sensors have been identified that have potential for monitoring oil discharged at an offshore facility. Of these we judged the Wright and Wright Infrared Oil Film Monitor the best candidate considering all criteria including price, particularly because the technique is proven and the instrument is commercially available.

We judged the laser fluoroscencing to be the most likely technique to work if the Wright and Wright Oil Film Monitor proves inadequate. Appendix A presents a proposed design for a laser fluorosensor for use as a sentinel monitor in the offshore.

3.0 TECHNICAL SUMMARY OF EVALUATED SENSORS

3.1 Wright and Wright Infrared Oil Film Monitor

The sensor consists of a transmitter, receiver and associated electronics. The transmitter is a tungsten halogen bulb and reflector which focuses an intense beam of light onto the water surface. The receiver contains a chopper and electronics. The chopper contains filters which sample in the two wavebands while the electronics amplify, smooth and ratio the signals. An example of a typical configuration is shown in Figure 17.

Wright and Wright Oil Film Monitors have been deployed in drainage channels from refineries and oil transfer stations for many years. Most deployments involve installation of the sensor at a height of 1.8 metres above the water surface, which is clearly insufficient for deployment on offshore platforms. A new design of the Infrared Oil Film Monitor incorporating thermo-electric cooling of the detector to improve instrument sensitivity has since been built but not extensively tested. The primary objective of the present program as it pertains to the Infrared Oil Film Monitor, was to evaluate the operational characteristics of this new device at greater heights and with a variety of surface wave conditions. The specification of this instrument as outfitted during the program are given in Table 5.

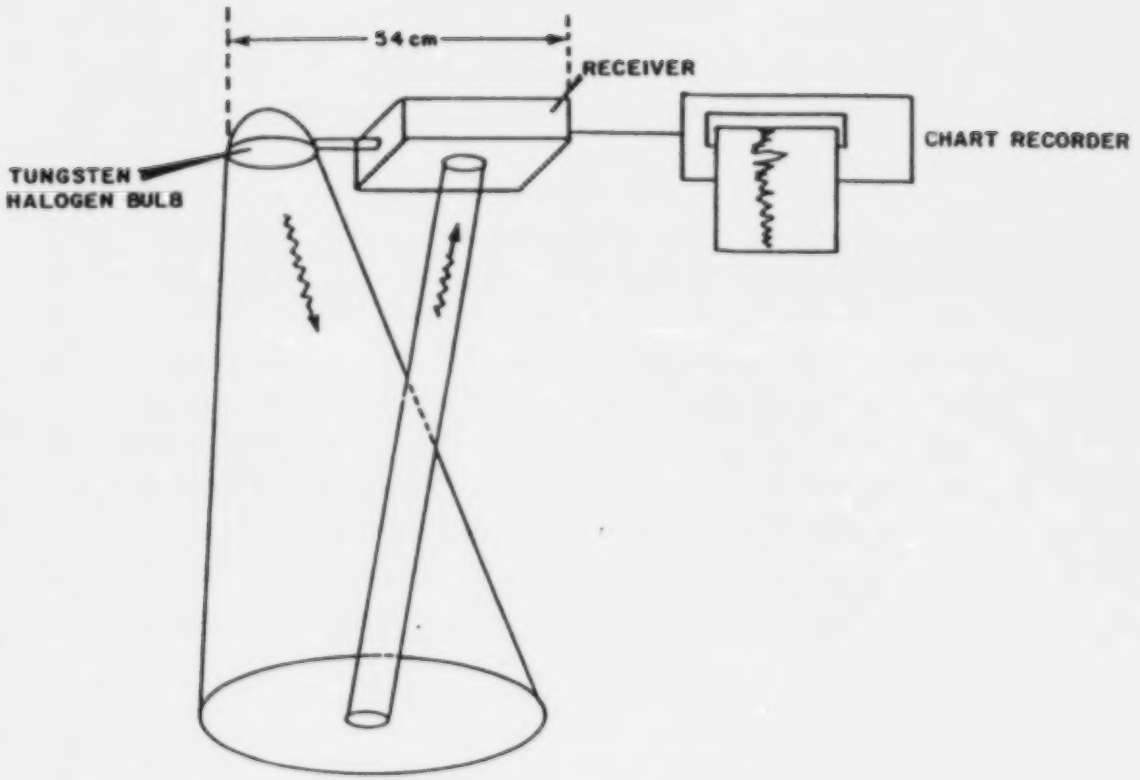


Figure 17. Infrared Oil Film Monitor (from Martec 1985)

TABLE 5

SPECIFICATIONS FOR WRIGHT AND WRIGHT INFRARED OIL FILM MONITOR

Minimum film thickness detected	0.1 micron average thickness
Area monitored	An area directly below the instrument with a diameter 0.05 times the height of the instrument above the water
Size	54 cm long x 30 cm wide x 22 cm high
Weight	8.2 kg with one transmitter
Outputs	0-10 VDC analog output
Operating temperature	-18°C to +38°C
Wavelengths detected	Narrow regions centered at 2.5 and 3.1 microns
Power requirements	105 - 125 VAC 60 Hz
Power consumption	
Transmitter	2 x 250 watts + 1 x 500 watt
Receiver	8 watts
Options	Film thickness discriminator to differentiate thin sheens or thick slicks (greater than 10 microns).
	Selectable criteria alarm to delay oil alarm until a preset duration is met.
	Multiple transmitters.
	Explosion-proof housing.

3.2 Barr and Stroud Thermal Imager

The thermal imager used during the evaluation program was the Model IR18 developed by Barr and Stroud Ltd. in the United Kingdom. This unit uses a curved mirror which sweeps the image across a line detector producing one complete image per sweep. The line detector submits parallel output to an electronic processor which stores the complete image and outputs it in raster format suitable for display on a standard video monitor.

The thermal imager consists of a telescope (2.5 or 9x), a scan head and the electronic processor. These components are packaged into a relatively compact unit which is environmentally sealed and quite robust. Additional equipment required to operate the imager are a power supply, the control unit, compressed air supply and data display, and storage system. The sensor configuration as used is shown in Figure 18 and specifications are listed in Table 6.

All sensor adjustments are set through the control box. The five position sensitivity switch can be used to select the temperature range displayed. It may be selected to show temperature ranges of 2, 4, 8, 16 or 32 degrees centigrade over the complete range of grey scales. It is used primarily to optimize the contrast for any particular view. Also available on the control box are gray level control and screen polarity switches. Once the correct sensitivity has been selected, gray level is used to range the selected temperature range up or down to optimize information content. This augments the automatic black level adjustment available on the imager. This automatic feedback circuit eliminates the need for continual black level adjustment when screen contrast is widely varying. The screen polarity switch allows for "normal" viewing (white is hot, black is cold) or "invert" viewing (white is cold, black is hot). Also included on the control box are the telescope selection switch (2.5 or 9x) and the ON/OFF switch.

The Barr and Stroud Thermal Imager senses thermally emitted infrared energy in the 8-14 um waveband. The sensor does not sense the actual or absolute temperature of objects but rather their apparent temperature.

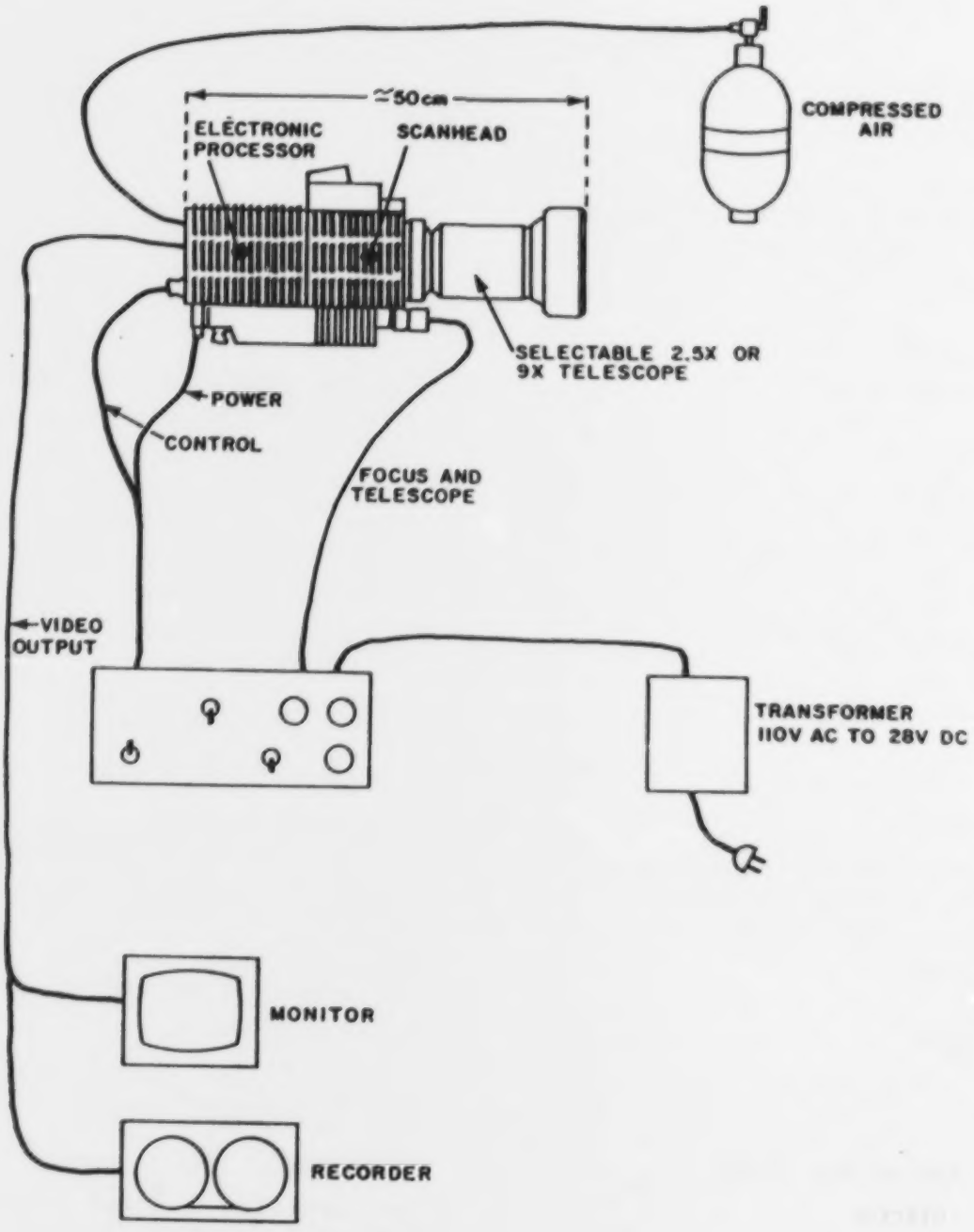


Figure 18. Barr and Stroud Thermal Scanner (from Martec 1985)

TABLE 6
SPECIFICATIONS OF THERMAL IMAGER

	Without Telescope	2.5x	9x
Horizontal Field of View	38.2°	15.4°	4.2°
Vertical Field of View	25.5°	10.2°	2.8°
Pupil Diameter	14.5 mm		

Maximum resolution of temperature (at 0.289 cycles/m radi)	0.17°C - 0.5°C
Detector	Serial/parallel Sprite cooled to 77°K
Spectral bandwidth	8.0-14 um
Video output	CCIR compatible 1 volt composite video (75 ohm load)
Display	525 TV lines/frame
Field rate	60 Hz
Frame rate	30 Hz
Cooling requirement	Clean air to AvP32 standard 1/8 in. BSP60° internal cone inlet
Inlet pressure	4500 psi max at 25°C 1500 psi min
Power supply requirements	24 volts d.c. nominal 20 volts min - 32 volts max
Power consumption	32 watts at 28 volts typical
Weight	
Scan head unit	3.5 kg
Electronic processor unit	2.2 kg
Power supply unit	1.1 kg
Total scanner	6.8 kg
Controls	Available on scanner rear panel or remote cable operation
Power	ON/OFF toggle switch
Sensitivity	5 position gain control providing nominally 2°C, 4°C, 8°C, 16°C, 32°C dynamic range displays
Temperature offset	"Black" level rotary control
Polarity	Two position control providing displayed temperature inversion (normal - white hot display) (invert - black hot display)

Apparent temperature is the product of the object's absolute temperature and spectral emittance. Spectral emittance is the efficiency of a target as a thermal radiator.

The detection of oil slicks on water bodies will therefore depend on either a real temperature difference or a difference in emissivity. Oils have a lower emissivity than water and therefore may appear as much as 3°C cooler at the same temperature.

A large number of factors may, however, result in actual temperature differences between the oil and water. The primary one is the oil may absorb sufficient solar energy to heat it above the temperature of the water. This has been shown to cause temperature differences as great as 10°K. A temperature differential may result from oil having a lower thermal conductivity than water. This may produce a positive or negative relative temperature depending on whether the water temperature is above or below the temperature of the air. The oil may retain its source temperature for a short period of time. Increased or decreased evaporative cooling of the surface can also occur depending on the volatility of the oil.

Some form of temperature difference generally results and may be used to differentiate the oil from the water. Difficult times for oil detection in the thermal IR region appear to be at dawn and dusk where air-water temperature differences are small and solar heating is minimal.

Oil thickness plays an important role in the detection of oil slicks with thermal IR imagery. The thermal energy detected by the sensor is emitted by a surface layer of finite thickness. If the slick is thinner than this layer, the result is that the sensor is seeing both water and oil. As well, if the slick is very thin, solar heating may not dominate since the oil is unable to absorb sufficient energy. The difficult problem of interpreting IR imagery is too lengthy for this report and the reader is referred to O'Neil et al. (1983) for a complete summary.

3.3 Moniteq 'Oilspills' Vapour Sensor

The Oilspills sensor is a type of specialized radiometer operating in the near infrared region. It does not detect the oil spill itself but rather the vapour plume that is evaporating from the slick. The oil spill must be of sufficient thickness, areal extent and volatility to permit sufficient evaporation from the slick to produce a detectable vapour plume.

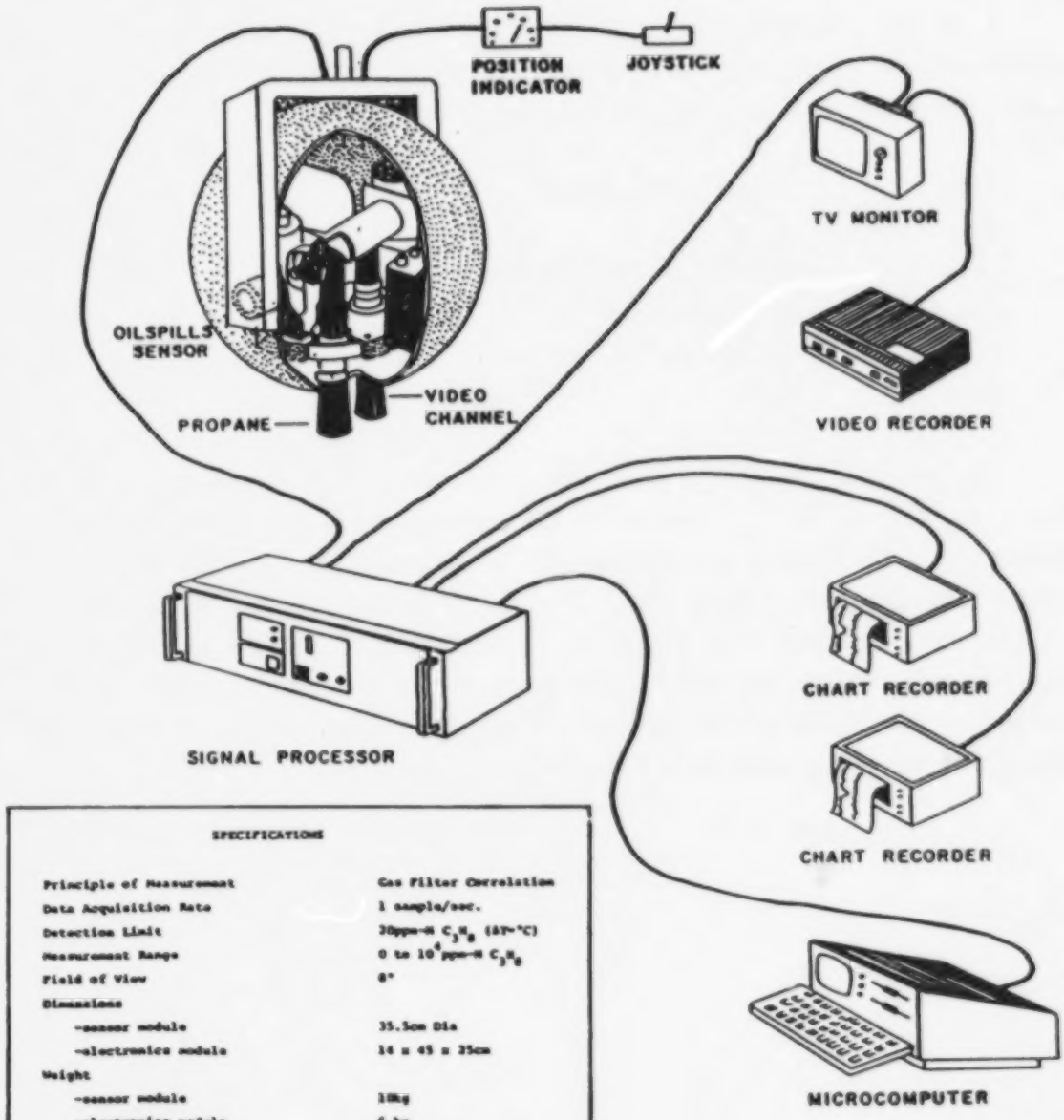
A non-dispersive filter correlation technique is used as the basic measurement technique. The instrument views the infrared background radiation and compares this with the same radiation passed through a target gas cell. The target gas cell contains gas with similar emission/absorption characteristics to the gas which is to be sensed. The background signal and the signal through the target gas cell are measured and electronically balanced. This balance is then upset when a gas with similar absorption/emission characteristics to the target gas is present in the sensor field of view.

The target gas used in the Oilspills sensor is propane. It was chosen since it has similar absorption/emission characteristics to those gases which emanate from most oil slicks. Propane has a well defined infrared spectra which is distinct from normal atmospheric constituents such as nitrogen, oxygen and water vapour.

The instrument uses a single optical train which is passed through a chopper wheel containing the target gas cell, a neutral filter and a reference blackbody. The detector is cooled by liquid nitrogen and senses in a 0.8 um waveband centered at 3.4 um. The Oilspills sensor and associated support equipment are shown in Figure 19.

Note:

There is a difference of opinion as to the primary source of the radiation measured by the device. Moniteq, the manufacturer, maintains that the source is thermally-emitted radiation and that a temperature difference of several degrees centigrade between the ground and the vapour is required for the vapour to be detected. The scientific authority who commissioned the building of the Oilspills sensor maintains that no temperature difference is required since the radiation being measured is not thermal but spectral. The difference in opinion is important: on the one hand the instrument would not operate wheneven temperatures are constant (usually morning and evening); while on the other hand the sensor would not operate at night. This issue needs to be resolved.



SPECIFICATIONS

Principle of Measurement	Gas Filter Correlation
Data Acquisition Rate	1 sample/sec.
Detection Limit	30ppm-M C_3H_8 (87°C)
Measurement Range	0 to 10^4 ppm-M C_3H_8
Field of View	8°
Dimensions	
-sensor module	35.5cm Dia
-electronics module	14 x 45 x 35cm
Weight	
-sensor module	18kg
-electronics module	6 kg
Operating Temperature	0 to +40°C
Power Requirements	28 VDC; 100 watts
Outputs	RS-333C, 7 bit ASCII, 300 baud
	0 to 10 volt analog
	Visual/Audio Alarms
Detector Coolant	Liquid Nitrogen

Figure 19. Oilspills Sensor and Associated Electronics (from Martec 1985)

3.4 Photographic Documentation

A 35 mm camera was used during the evaluation program for documentation purposes. The camera was equipped with flash, motor drive and annotation back. The specifications for the camera are as follows:

Camera	Minolta Maxxum 9000
Film Size	35 mm
Lens	Minolta AF 35-70 mm f/4.0
Flash	Minolta 4000 AF
Film	Ektachrome 400 ASA slide film
Filters	None

The shutter release cable was connected to an event control box. The event controller is a switching device that triggered the photographic camera and activated the video recorders for both the Barr and Stroud Thermal Imager and the Oilspills sensor. The event controller can be programmed to include an initial time delay at the beginning of a sequence, determine the interval between photographs and trigger a given number of photographs. The device controlled all photography and video recording and proved invaluable during the automatic recording phases when no one was at the site.

4.0 METHOD FOR EVALUATION OF SENSORS

Anticipated deployment of a sentinel water surveillance system would involve mounting one or more sensors on an offshore platform. The system should be able to operate in all environmental and illumination conditions and require a minimum of maintenance.

Under this contract, evaluation of equipment to fulfill these requirements involved tank testing to define the individual sensor performance characteristics under controlled conditions, followed by outdoor testing in simulated offshore conditions. Tank testing was done at the tower tank at Dalhousie University and outdoor testing was conducted at Esso Resources Dartmouth refinery.

4.1 Tower Tank Testing

The tower tank is housed inside the Oceanography building at Dalhousie University, Halifax, Nova Scotia. The tower tank is a silo-shaped deep tank which has a depth of 10.5 m and a diameter of 3.7 m. Salt water for the tank is withdrawn from the ocean and may either be heated or chilled before introduction into the tank. Illumination within the tank is provided by two metal halide lamps which produces surface light levels at the top of the tank of approximately 13% of normal noon day summer sun. A schematic of the tower tank facility if provided in Figure 20.

At the tower tank, all the sensors were attached to a cage which was lifted over the tank by a winch and trolley system. The cage was lowered to the upper rim of the tank and tied into position where it remained for the duration of the tests. Water was introduced into the tank up to the bottom of the first access port. The water depth was 0.5 metres, and sensors were 10.0 metres above the water surface.

The tests conducted at the tower tank were used to define sensor characteristics under a variety of oil concentration and air and water temperature regimes. A floating oil boom was constructed and placed on the water surface

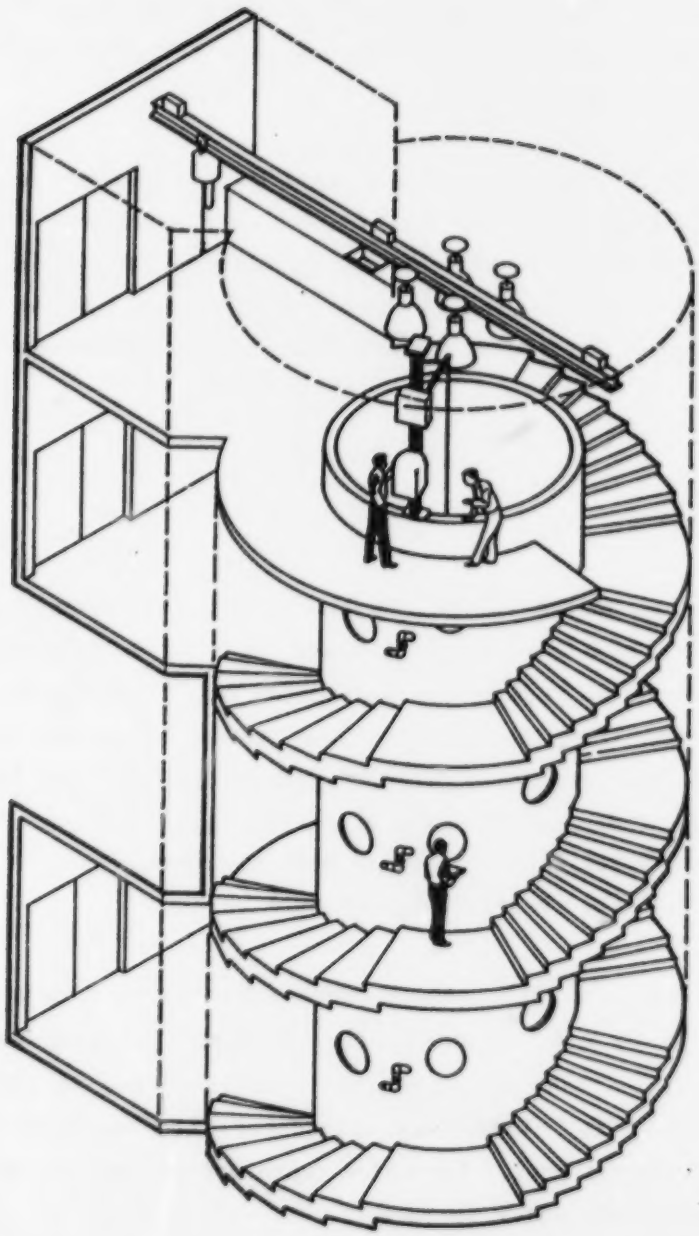


Figure 20. Tower Tank Facility, Dalhousie University

to limit the areal extent of slicks created within the tank. Water temperature could be specified when filling the tank, and air temperature could be crudely modified by positioning a fan in the lower access port and blowing warm air into the tank. As well, the fan could be positioned to blow across the water surface to create waves up to 2.5 cm high.

4.2 Refinery Testing

Field testing was conducted at Esso Resources Canada Dartmouth refinery, near the outfall from the API separators. The separators are used to treat ballast water, surface runoff from the tank farm, waste oil and excess products during plant upsets. The effluent volume handled varies dramatically depending on plant operation and weather conditions. Some entrainment of oily products into the discharge waters occasionally occurs, but these are handled by a permanent oil-retaining boom which encloses an area of the harbour.

This is a good location for testing oil detection devices since oil films are usually observable inside the boomed area. Experiments were based primarily on whether the sensors could detect the oil under a variety of environmental conditions.

The sensors were mounted on an aerial work platform as shown in Figure 21. The platform had a maximum operating height of approximately 20.0 metres during high tide. From the elevated platform, all operating cables were led down to a nearby trailer which housed the instrument controls and data display and storage devices.

As shown in Figure 22, the aerial platform was positioned such that it was possible to swing the instrument array both inside and outside the boomed area. It was important to have the ability to observe both oiled areas as well as background conditions. Many oil detection devices are only able to detect oil if a change in condition is evident.

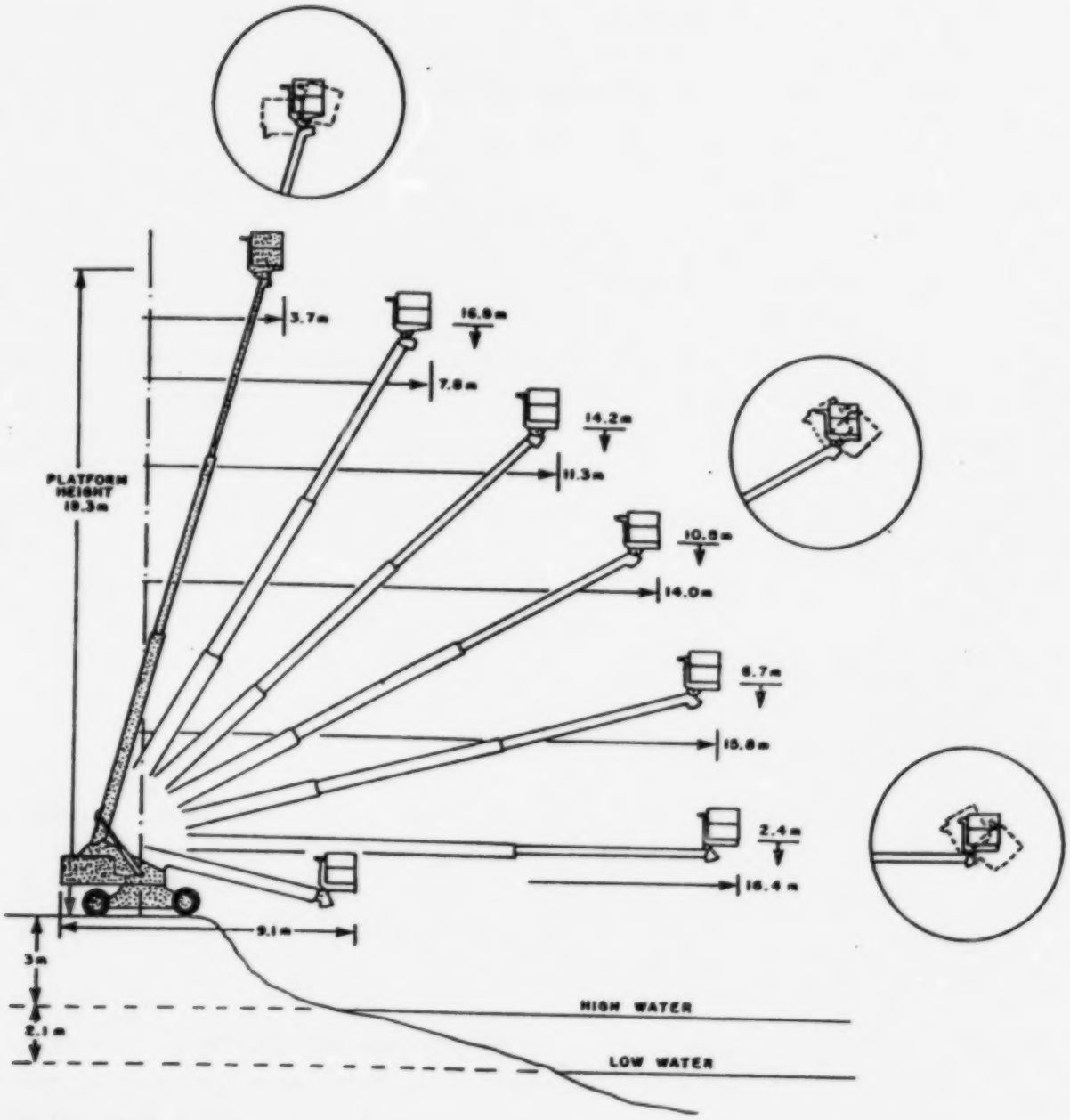


Figure 21. Aerial Work Platform (from Martec 1985)

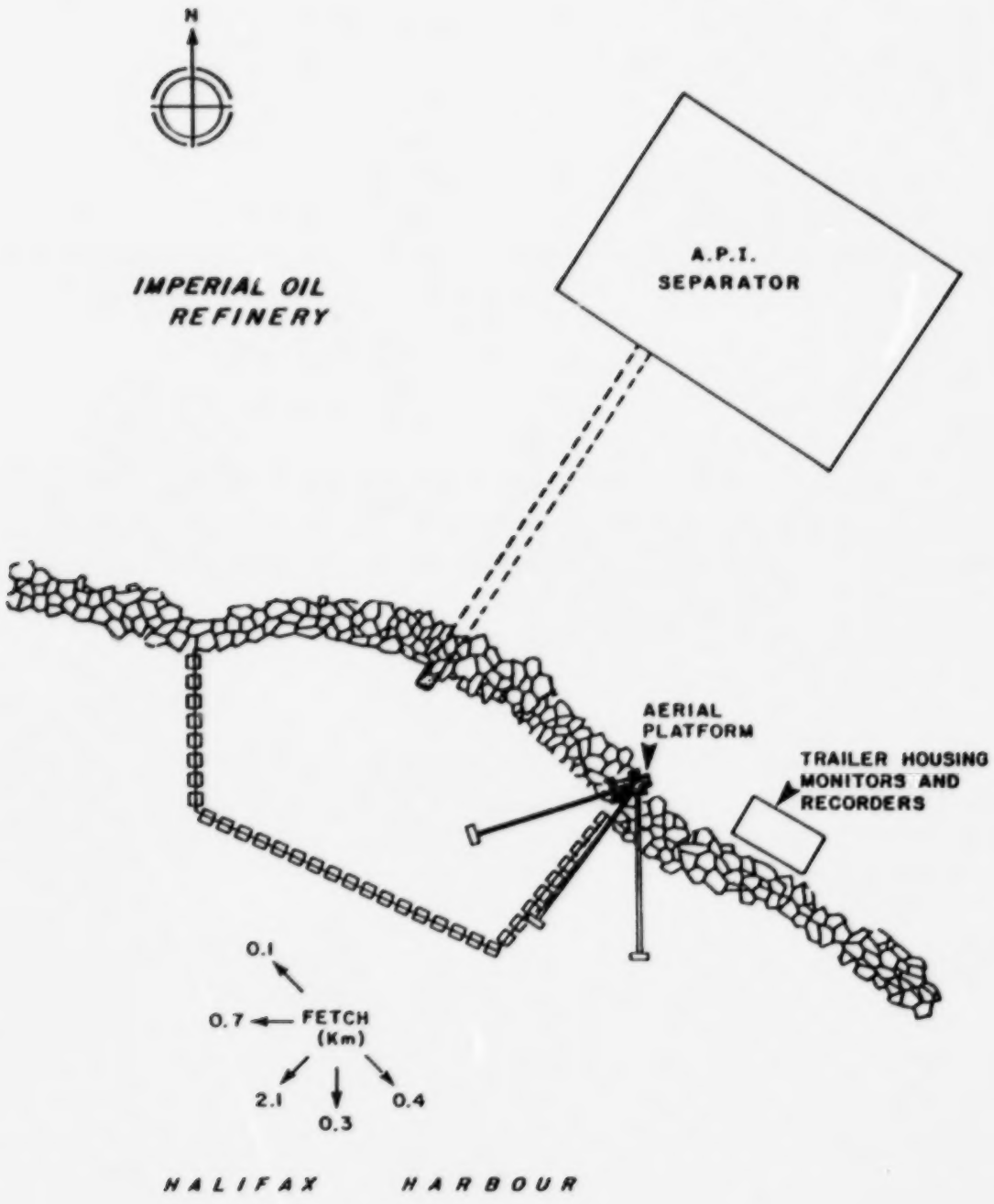


Figure 22. Site Layout at Refinery (from Martec 1985)

The outdoor testing at the refinery was broken down into manned and unmanned operational phases. Initially, the site was manned and a large number of tests were run. This phase was used to evaluate the oil detection characteristics of the sensors under realistic conditions. The correct operation of the automatic control box was also verified.

The unmanned phase involved the automatic operation of the sensor array. The system would run continuously and be checked 2 or 3 times a day by a technician. These checks were to assure no malfunction had occurred and to refill equipment with liquid N_2 and compressed air as required.

4.3 Program Summary

The sensor evaluation was begun on 22 November, 1985 and continued through to 11 December, 1985. Over this period, 32 hours of video tape recordings, over 200 hours of chart recordings and 216 35 mm photographs were taken. In addition, a number of diskettes containing Oilspills data were collected and outputted as computer plots. A brief summary of the field program is given in Table 7.

No equipment malfunctions occurred during the evaluation and the program ran quite smoothly. Data was collected during a range of environmental conditions at the refinery, although the site did not experience any large wave conditions.

TABLE 7

SUMMARY OF TESTS AND RECORDING TIMES

Friday, 22 November

All equipment installed at tower tank except Wright and Wright which arrived Sunday.

Sunday, 24 November

Personnel from Wright and Wright, and Moniteq arrived. Wright and Wright sensor installed on platform.

Monday, 25 November

Full day of testing at tower tank undertaken. Tested with a variety of oil types and air and water temperatures.

Tuesday, 26 November

Full day of testing. Wright and Wright observing oil well if in a continuous film. Oilspills data inconclusive. Barr and Stroud Imager detecting oil nicely.

Wednesday, 27 November

Morning spent testing. Oilspills did not detect oil but did detect propane when introduced into bottom of tank. Other sensors detected oil well, but wave generation obliterated Wright and Wright signal. Afternoon spent moving equipment over to refinery, Wright and Wright sensor remained at tower tank for further testing.

Thursday, 28 November

Most of day spent installing equipment at refinery. Wright and Wright sensor stayed at tower tank and testing continued into evening.

Friday, 29 November

Entire day spent conducting tests with different oil types and operating heights. Wright and Wright sensor moved to field site.

TABLE 3 (Cont'd)

Tuesday, 3 December

Intensive testing of Wright and Wright during early morning and late afternoon. Working well. Wright and Wright left operating overnight.

Wednesday, 4 December

Site visited in morning. Remaining sensors turned on. Returned in evening and shut everything down.

Thursday, 5 December

Morning spent running a wide variety of tests. Still no conclusive results with Oilspills. Barr and Stroud Imager difficult to interpret. Wright and Wright signal varies widely if platform not positioned correctly, but works reliably when platform is correctly positioned.

Friday, 6 December

Morning spent primarily fine tuning and testing Wright and Wright sensor.

Tuesday, 10 December

Conducted a variety of tests primarily concentrating on the Wright and Wright sensor, which was easily outperforming the other two sensors in the detection of oil.

Wednesday, 11 December

Tests with Oilspills using propane. Then disassembled equipment for shipment back to sources.

5.0 RESULTS AND DISCUSSION OF TANK TESTING

Three full days were spent evaluating the sensors at the tower tank. The results obtained with each sensor are discussed in turn below.

5.1. Wright and Wright Infrared Oil Film Monitor

The Wright and Wright sensor as tested used three light sources and a receiver. Each lamp was individually aligned with the detector using an oscilloscope to measure signal strength. The calm water surface present in the tower tank allowed this process to proceed quite quickly. The complete alignment took approximately one hour and was accomplished by a Wright and Wright technician. A few internal adjustments were then undertaken which took approximately an additional one-half hour.

After the initial setup, the instrument required no further adjustment. Signal levels remained very high during all the tests. The oscilloscope was set up to monitor both channels simultaneously. This permitted visual interpretation of the data in real time, since it bypassed the smoothing routines (one minute integration) in the electronic processor. The oscilloscope became useless however whenever even small waves were created on the water surface. In this situation, signal levels varied so widely that real time interpretation from the oscilloscope was impossible and the signal averaging provided by the processor was required.

The Wright and Wright sensor did not appear to be affected by changes in air or water temperatures. Although signal levels will drop with increasing atmospheric water vapour content, this parameter did not change signficantly during the tower tank tests. The sensor showed different sensitivities to various oil types and it is believed that oil spreading characteristics were responsible for this. Oils that did not spread effectively under a calm wave environment were not detected except when sufficient oil was present to cover most of the water surface area.

Diesel oil did not spread well but tended to coalese into lenses of oil which were of considerable thickness. Crude oil and motor oil spread much better and were detected at much lower concentrations. Data on exact oil thicknesses that were detected were difficult to obtain because of the variability in slick thickness. From colour plates contained in Fingas et al. (1979), it did appear that if the minimum film thickness over the entire area was approximately 0.4 microns or greater, then a positive response would be recorded. Slick thicknesses less than this tended to have reflection characteristics similar to that of water.

Figure 23 is a sample of the Wright and Wright ratio channel output for the 25 and 26 November tests at the tower tank. During the 25 November test, 100 mL of diesel oil was released inside of the boomed area producing an average oil thickness of approximately 10 microns. Between 2105 and 2125 hours, the oil retaining boom containing the oil slick was moved several times inside and outside the sensor's field of view. As shown, the sensor responded to the presence of oil with signal levels varying between 0.5 volts for clean water and 1.5 volts for oil.

The 26 November tests shown in Figure 23 involved the introduction of 10 mL of crude oil into the boomed area. Though this addition was only one-tenth of the amount of diesel oil used in the previous tests, the crude had much better spreading characteristics. The crude spread out covering the entire boomed area and produced a ratio channel response of 2.0 volts.

At 1242 hours, the lamps on the Wright and Wright were turned off to facilitate a slight readjustment after the sensor had been bumped. The sensor responded by showing a large positive oil signal. Although the sensor has circuitry to warn operators of major malfunctions such as burnt out lamps, it is interesting to note that the sensor did respond with a false oil detection signal when the lights were turned off.

To test the response of the sensor to oil in ice, crushed ice was discharged onto both the clear water surface and the oiled surface. The sensor was not influenced by the ice and gave a strong and correct response under both the clear water and oil slick conditions. It should be noted

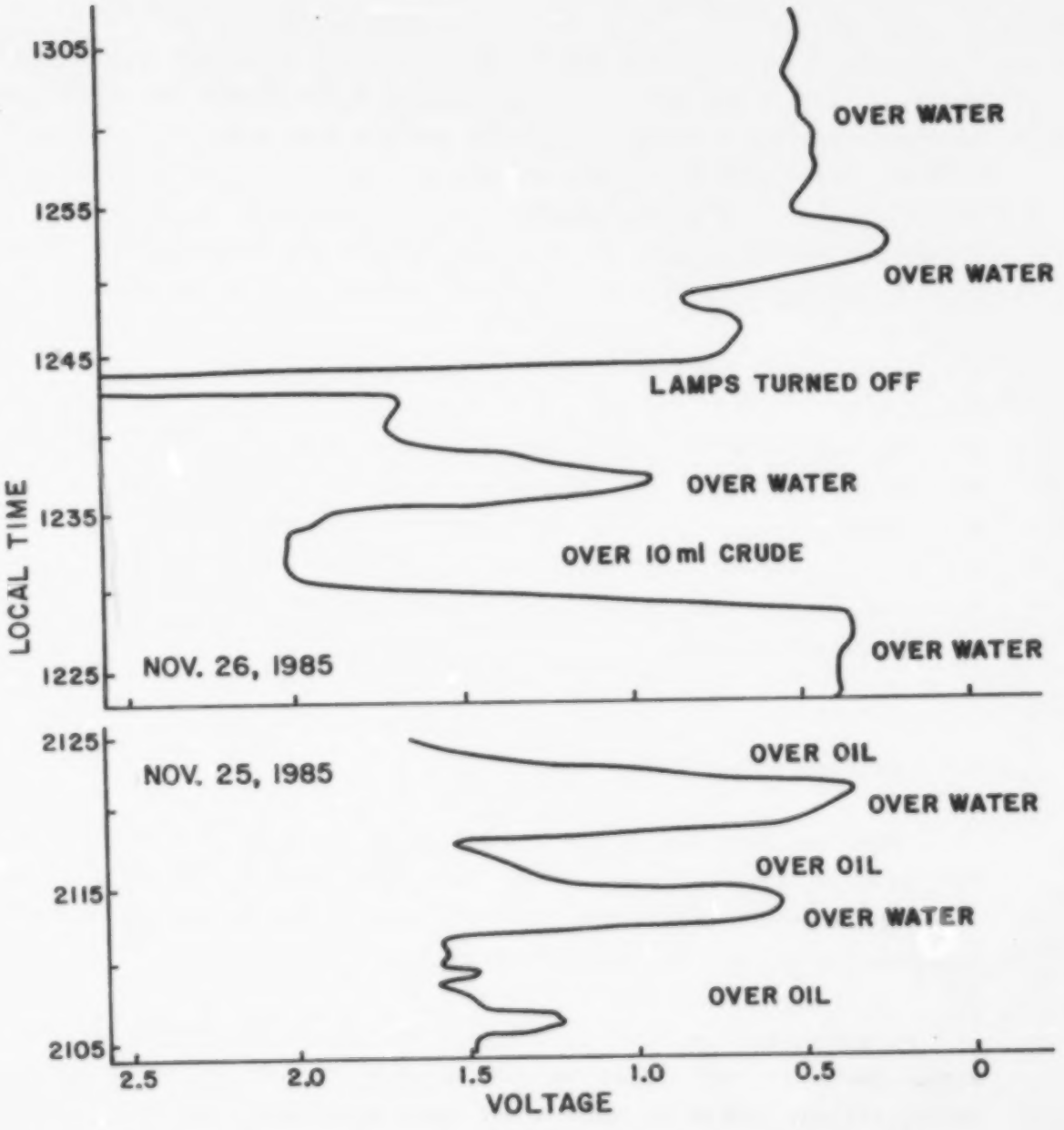


Figure 23. Ratio Channel Output from Infrared Oil Film Monitor November 25 and 26, 1985.

that under each situation the upper surface of the ice was wetted with either oil or water.

Another test was conducted in which a number of wooden boards were positioned within the sensor's field of view in an attempt to ellicit an incorrect response. The sensor did not produce a false oil signal. Tests by White (1976) with the Wright and Wright sensor have shown that as long as the foreign material is wetted, the sensor response will be that of the wetting medium, either oil or water. This is the result of the sensor only viewing a thin surface layer and not "seeing" into the medium.

To summarize, the Wright and Wright Infrared Oil Film Monitor:

1) required a relatively short setup time and no maintenance once installed;
2) defined continuous slick and sheen effectively;
3) effectively operated at a 10 m height with minimal waves;
4) was not influenced by floating ice or debris;
5) required that the slick cover greater than about 80% of the surface in the sensed area.

5.2. Barr and Stroud Thermal Imager

With the Barr and Stroud Thermal Imager, the results at the tower tank were positive. Oil was always detectable, and at all times it had a higher apparent temperature than the water. The reason for the warm appearance of the oil requires some discussion.

As stated earlier, oil has a lower emmisivity than water so it should appear cooler if both are at the same temperature. During the tower tank tests, oil was stored at ambient air temperature which varied between 14 and 18°C. Water temperature within the tank varied from 9 to 14°C. Although the oil could have been up to 9°C warmer than the water when introduced onto the water surface, the oil films created were so thin that the oil temperature would equilibrate with that of the water quite quickly. Emissivity, then, does not explain the warm appearance of the oil.

Oil may also be detected due to its lower thermal conductivity. The oil can insulate the water surface, producing an oil film which appears cooler or warmer than the adjacent water, depending on whether the air temperature is above or below that of the water. As stated earlier, the air-water temperature differences inside the tower tank were small, as were the thicknesses of the oil films created. Oil slick identification utilizing the lower thermal conductivity of oil was therefore assumed to play a minor role during the tower tank tests.

Radiative heating of the oil was also assumed to play a small role in the appearance of the oil using infrared imagery. As stated earlier, the two metal halide lamps produce illumination levels at the top of the tank of approximately 13% of normal noon day summer sun. The lamps from the Wright and Wright sensor had a combined power of 1000 watts, but the detection of oil or its appearance in the thermal infrared did not appear to be influenced by the presence or absence of these lights. The main factor in the warm appearance of the oil in the thermal infrared region was due to a reduction in evaporative cooling by the oil. To understand this viewpoint more clearly, further discussion of thermal infrared imagery over clean water is required.

During the present phase, and earlier work done by Martec (1985), close range IR imagery of clean water surfaces outdoors was noted as producing a great amount of detail of the water surface, whereas none was evident in the visible region. Features of approximately the scale of a wave ripple covered the entire water surface, and moved in a random motion. These features were slightly darker than the water and had a wispy appearance. They are believed to be locations of concentrated evaporative cooling caused by micro-scale wind events at the air-water interface. The appearance of these features was very prevalent during the tank testing when the fan was blowing over the water surface. As small quantities of oil were added to the water surface, these features were erased by a featureless slick which has a slightly higher apparent temperature. Slicks as thin as 0.4 microns were clearly observable. Apparent temperature differences within the slick were not observable.

Horvath et al. (1970) has collected measurements of attenuation coefficients of a number of crude oils in the wavelength region 8.5 to 12.5 um and has found them to be near 0.0005/micron. These data indicate that a 320 um thick oil layer is required for 80% of the thermal radiation to be emitted from the oil and 20% from the underlying water. Therefore, for the thin oil films created in the tower tank, the IR Imager was detecting primarily the water beneath the oil rather than the oil film itself. Oil films were only detected because they reduced the evaporative cooling of the water beneath them. Emissivity differences or radiative heating may be assumed to be secondary factors.

5.3 Moniteq Oilspills Vapour Sensor

During the tank testing phase of the experiments, the Oilspills sensor did not respond to oil slicks on the water surface. The only positive response occurred on the last day of the tests when small amounts of propane were introduced into the tank. The tank tests indicate the sensor is unable to detect vapours emanating from small volumes of oil, even in a system with restricted air circulation.

The Oilspills sensor as outfitted during the tower tank tests was operated from a height of 10 metres above the water surface pointed directly downwards. Sensor output was available from a television monitor in both graphical and numerical output (see Plate 1). As well, all data was simultaneously logged onto a micro-computer which then stored the information on diskette. The information could later be retrieved from diskette and plotted.

Throughout the tower tank tests, a wide variety of tests were run using crude, diesel and motor oil. No conclusive results were obtained. Signal levels seemed to vary widely for no apparent reason. Figure 24 contains Oilspills output taken on 26 November from 1639 to 1710 local time. The first 80 data points show a large drop in the gas signal which we attribute to instrument warmup. The instrument does require some time for the gas correlation cell to arrive at operating temperature. Figure

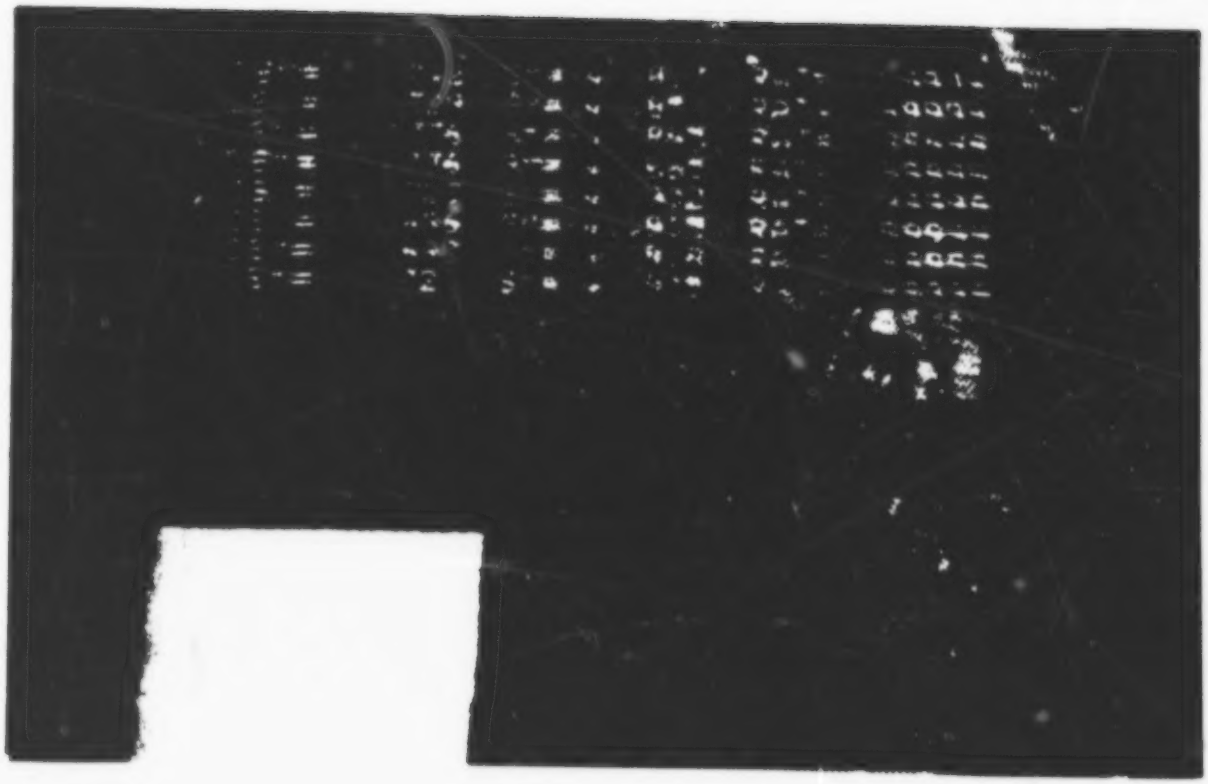


Plate 1. Oilspills Video Display Format

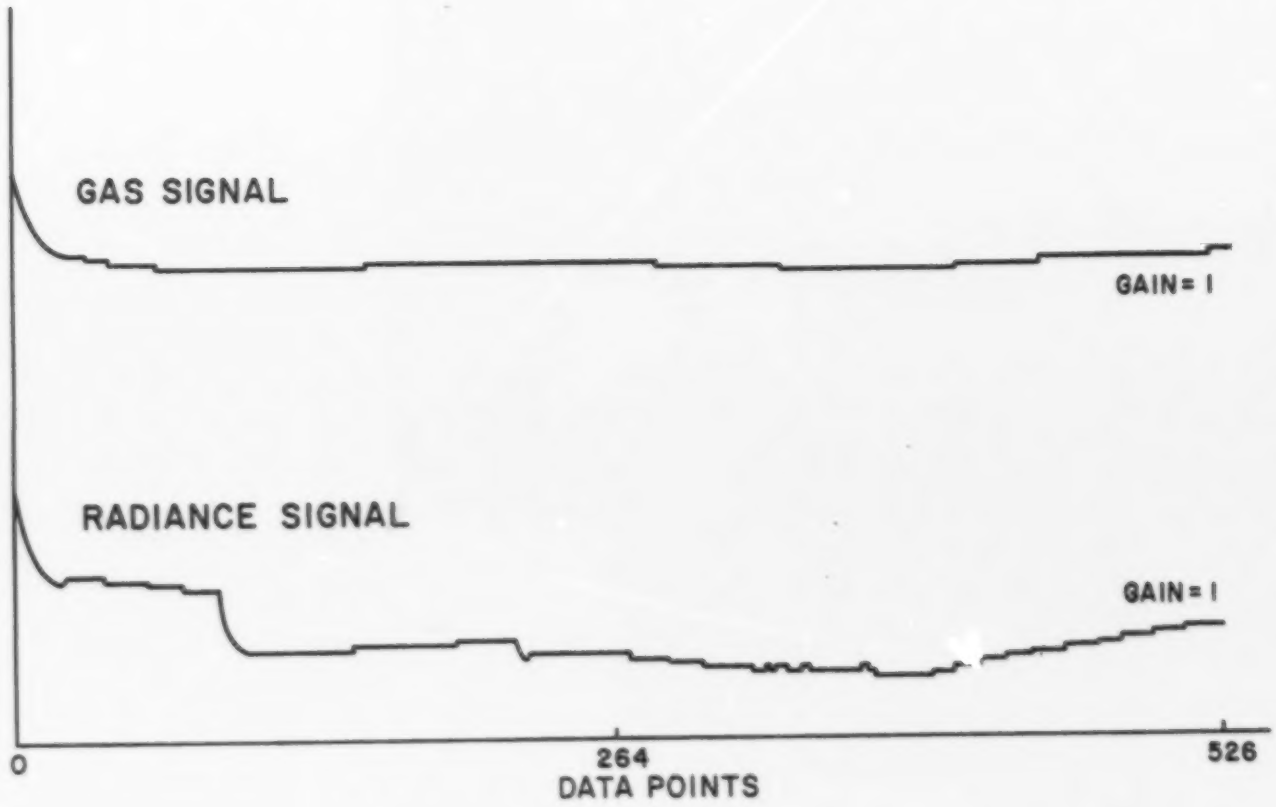


Figure 24. Oilspills Output - November 26, 1985

25 is the same data as shown in Figure 24 minus the first 80 data points. Removing the large peak at the start of the plot allows the vertical scale for the remaining data points to be expanded. Figure 25 shows large fluctuations in gas channel output not observable in Figure 24. The cause of these fluctuations is not readily apparent when looking at the test conducted. However, if one compares the radiance and gas channel signal, they both display identical trends.

The introduction of ice into the water resulted in a large drop in the radiance channel. This resulted in a drop in the gas signal. After the ice had been added, both signals increased until the point at which 10 mL of diesel oil was added onto the water surface. A heater gun was turned on to increase oil evaporation. Although vapours were clearly evident to the nose, they were not detected by Oilspills. Temperatures at the time were: air temperature in tank 12.0°C; air temperature outside port hole 13.5°C; water temperature 10.8°C.

The only instance where the instrument did register a correct response is shown in Figure 26. The instrument warm-up period has been removed to assist in easier interpretation. Good baselines were obtained until ice was introduced at data point 84. The ice lowered both the radiance and gas levels and both remained level until the propane was introduced by opening the valve on a propane torch. The first blast lasted for 30 seconds while the second lasted 20 seconds. Both produced a significant drop in gas signal levels. It may be important to note that this was one of the few instances where a change in gas signal could not be traced back to a change in radiance signal.

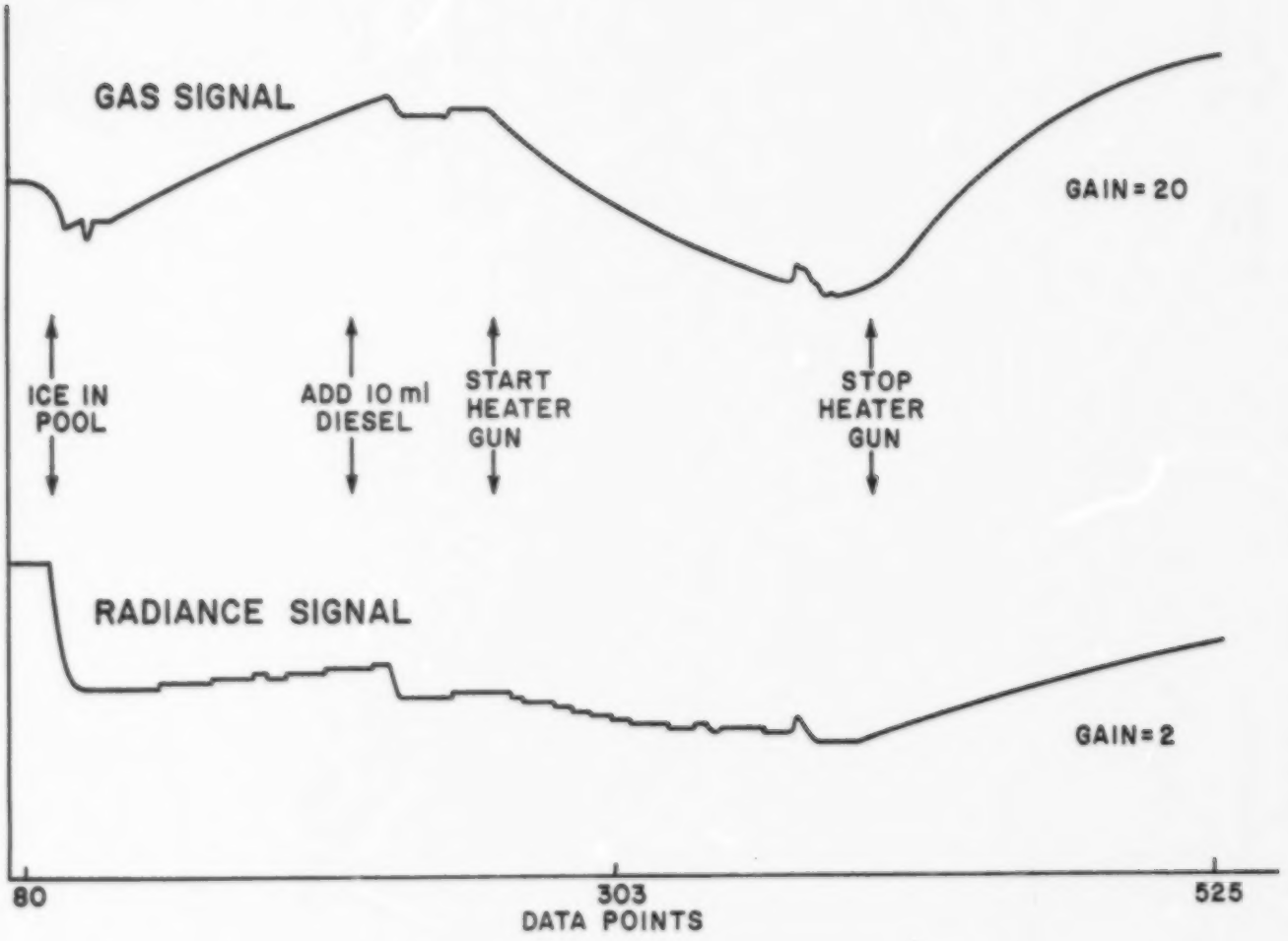


Figure 25. Oilspills Output - November 26, 1985

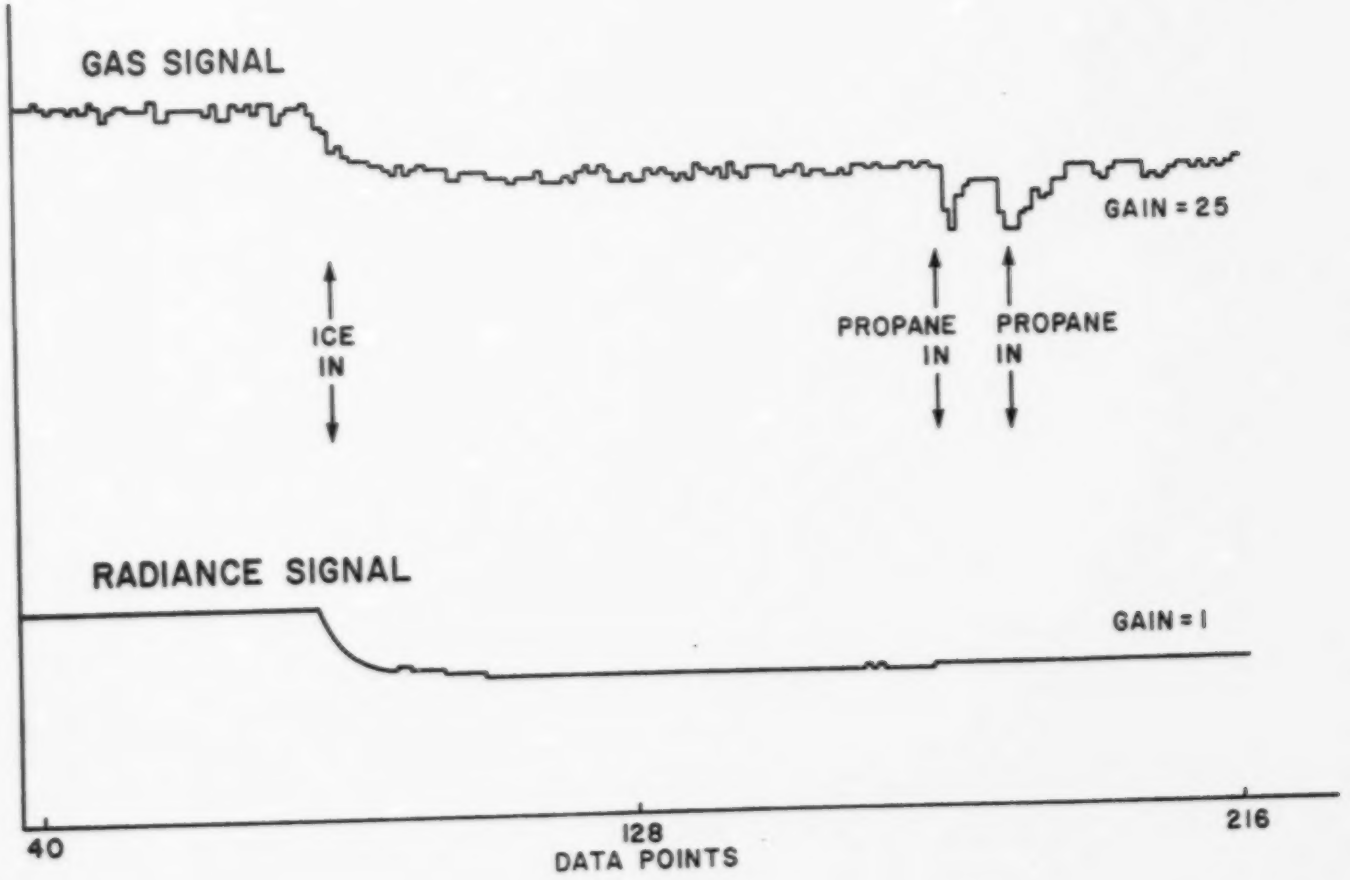


Figure 26. Oilspills Output - November 27, 1985

6.0 RESULTS AND DISCUSSION OF FIELD TESTS

Once testing was concluded at the tower tank, the oil sensors were moved to the Dartmouth Refinery for field testing. This phase began on 29 November, 1985 and continued through to 11 December, 1985. Over this time period, a considerable quantity of data was collected over a wide range of environmental and illumination conditions.

The field testing was broken down into a manual operational phase and an automatic recording phase. The manual operational phase involved the intensive operation of all sensors in an attempt to determine the operational parameters and oil detection limits of each unit under a wide variety of environmental and illumination conditions. The automatic phase involved the unmanned operation of the sensors. The automatic control box was used to switch on the relevant video recorders and take pictures at selected intervals. Output could later be analysed and used to assess the suitability of this type of system for offshore deployment. Maintenance requirements, mechanical reliability and oil detection reliability were the three most important parameters that were assessed during this phase.

6.1 Wright and Wright Infrared Oil Film Monitor

The primary objectives for field testing the Wright and Wright sensor were to evaluate the unit's oil detection abilities under wavey conditions and at operating heights greater than 10 metres. During the outdoor evaluation the unit was shown to be effective at discriminating slicks at the maximum operating height of the aerial work platform. Performance under large wave conditions could not be determined since the largest wave heights experienced at the site were 0.3 metres.

During field testing of the Wright and Wright sensor, the approach taken was to evaluate the oil detection abilities of the unit under different oil concentrations inside the boomed area. The operating height of the platform would be varied and a record of the wave conditions kept. A typical chart recorder output during the manned operational phase is shown in Figure

27. The plot is a record of the ratio channel from hours 1100 to 1300 on Thursday, 5 December, 1985. At the time the skies were clear, air temperature was -3.0°C, wave heights were approximately 5.0 cm and the wind was from the north at 5 knots. The plot shows a number of oil release events inside the boomed area. Small quantities of oil were released onto the water surface directly underneath the sensor in an attempt to elicit an instrument response.

The chart recorder output is summarized as follows:

1055-1105 Sensor over land and output steady at about 2.1 volts.

1105-1108 Aerial platform swung over water and signal varies widely as sensor passes overtop gravel, shoreline rocks, surf zone and then water. Signals ranged from 1.6 to 0.2 volts.

1108-1113 Over clean water outside boom. Signals vary from 0.15-0.25 volts.

1113-1119 Over sheen inside boomed area. Signals increased from 0.2 in clear water to 0.5 when overtop the sheen.

1119-1123 Over clean water and signals fairly steady at 0.1 volts.

1123-1132 Overtop sheen inside boomed area. Signals increased to 0.5 volts.

1132-1143 200 mL of oil from separators added to water surface underneath sensors. The signal increased dramatically to 2.0 volts and then leveled off around 0.5 as oil drifted out of range.

1143-1148 750 mL of crude oil added to water surface but this drifted away quite quickly and only produced a maximum response of 1.2 volts.

1148-1150 Fairly high baseline at 0.75 volts probably indicates contamination of the boomed area after repeated oil releases.

1150-1202 750 mL of diesel oil introduced over longer time period. A good response of 2.0 volts produced.

1202-1206 750 mL of gasoline released but a significantly smaller response than was produced by the oils.

1026-1215 750 mL of diesel oil released which produced a response of 2.0 volts.

1215-1224 Platform moved within boomed area to location near dock when oil was concentrated by the wind. Oil in this location was very thick. Response peaked off scale.

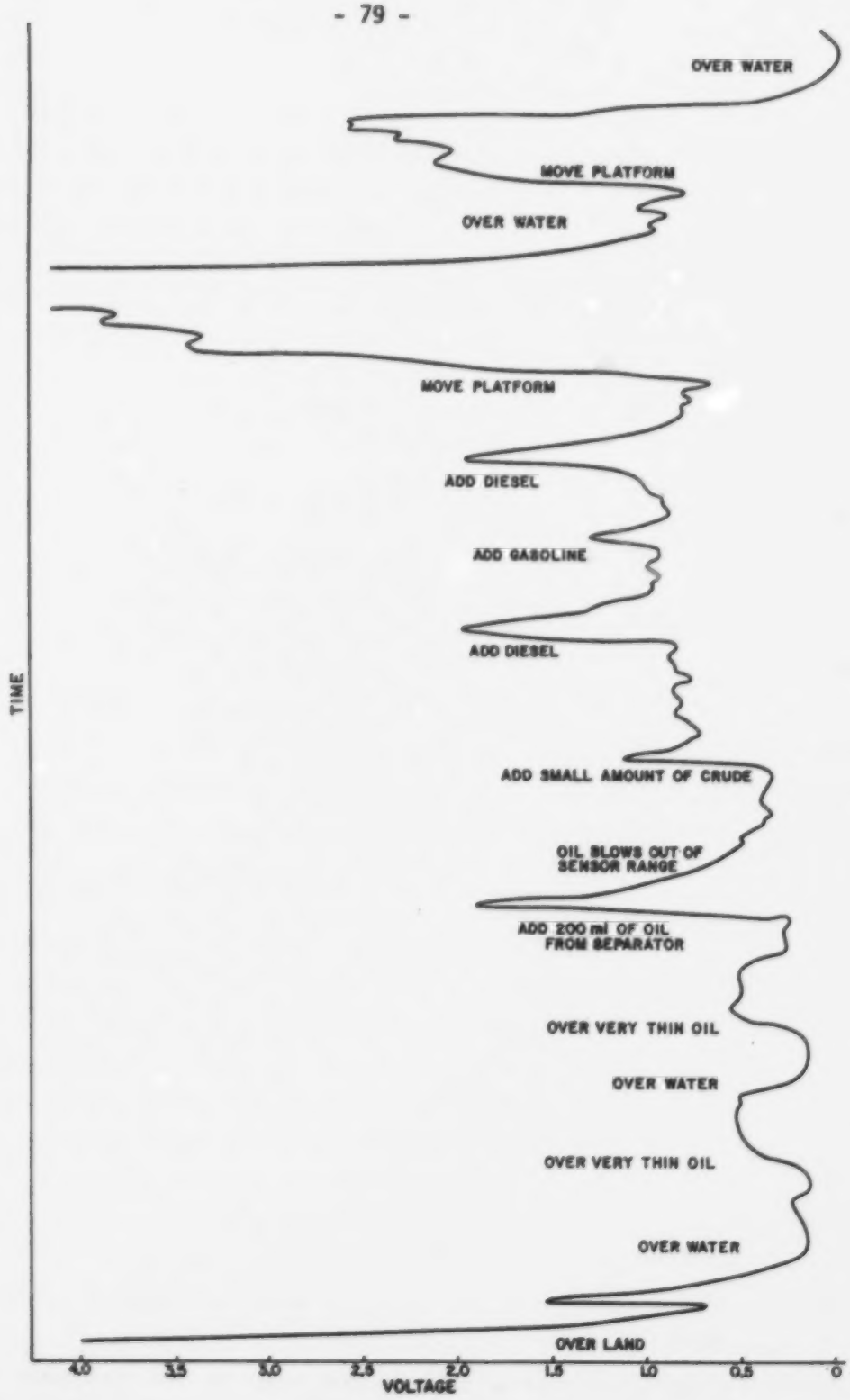


Figure 27. Ratio Channel Output from Infrared Oil Film Monitor - December 5, 1985

Operating height	10 m
Air temperature	-3°C
Water surface	heavily rippled
Skies	clear

1224-1233 Platform moved outside of boomed area but there is some leakage underneath boom which is producing a high response.

1233-1240 The platform was extended further from shore, but in process platform was tilted off vertical. This resulted in false oil signal.

1240-1254 Platform realigned in clean water and good baseline at about 0.1 volts produced.

A number of important features are evident from the analysis of this data. The most important feature is that under those environmental conditions, the sensor has the ability to discriminate between oil and water from a height of 10 metres. The sensor effectively detects a range of oils but does not appear completely effective for gasoline.

Figure 28 shows ratio channel output from the Wright and Wright sensor between 1005 and 1213 on 6 December, 1985. At this time the platform was operating from a height of 15 metres and the water surface was a flat calm. Ambient background levels varied between 0.1 and 0.5 volts, oil sheens tended to be between 0.5 and 1.0 volts and oil slicks above 1.0 volts. The instrument performed well at 15 metres and gave a positive oil response in every situation in which one occurred.

When operating the sensor from an elevation of 20 metres the sensor performed less well. Output from the ratio channel varied widely during leveling of the sensor. As well, the sensor was often observed to perform better under small wave conditions than when operated under completely calm water conditions. This was primarily due to an incorrect bias setting as explained in the following paragraph.

The sensor works by ratioing the received signals in two narrow wavebands centred at 2.5 and 3.1 microns. The outputs from Channel 2 (2.5 microns) and Channel 3 (3.1 microns) are measured, bias voltages applied and the resulting voltages ratioed. The reason for applying bias voltages is so that as signal levels decrease, the denominator of the ratio does not approach zero.

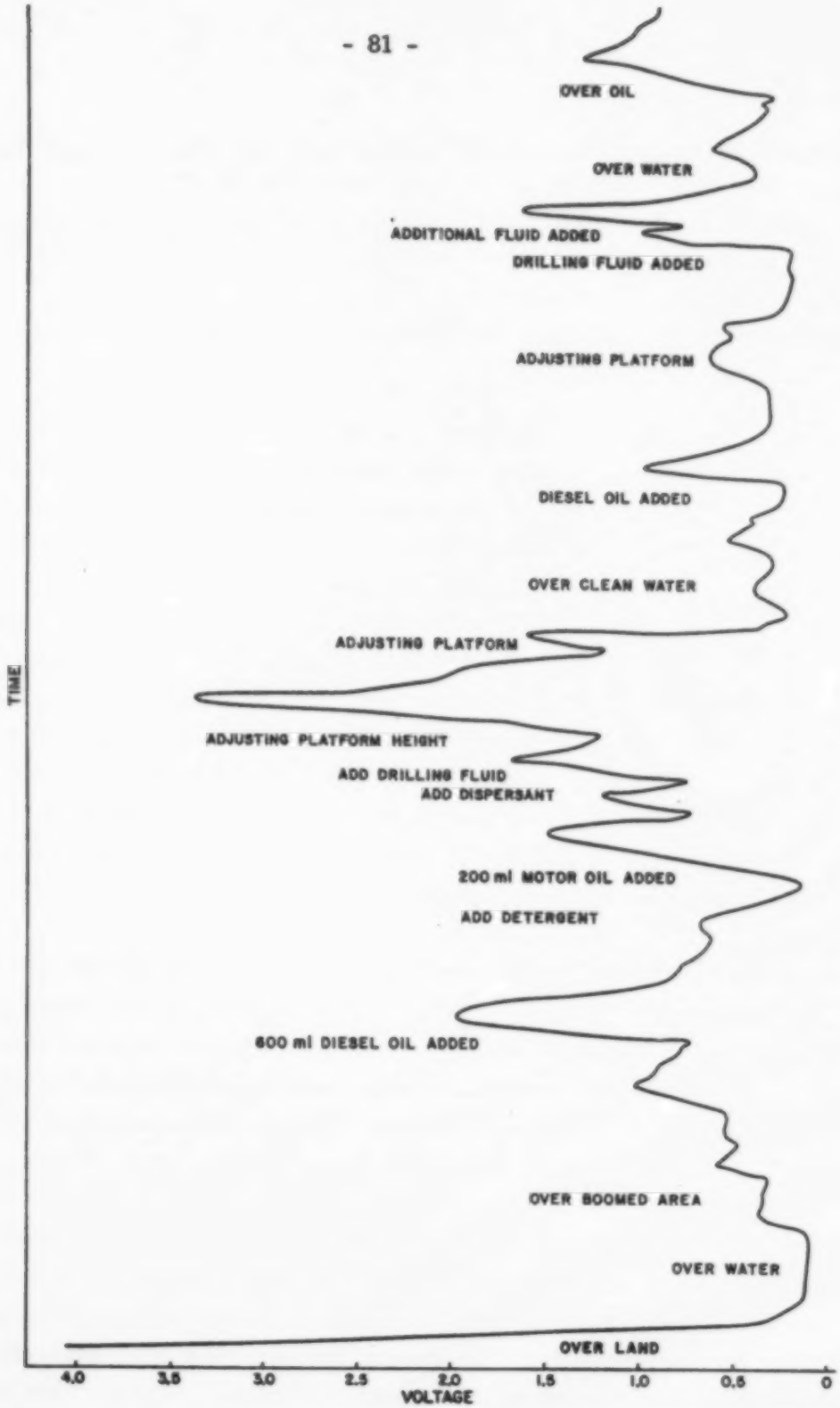


Figure 28. Ratio Channel Output from Infrared Oil Film Monitor - December 6, 1985

Platform height	15 m
Winds	<5 km/hr
Water surface	barely rippled

During the tank testing, these bias settings were adjusted for operation at a 10 metre height under small man-made wave conditions. No further adjustment was made during outdoor operation. The sensor performed well at 10 and 15 metre heights but when the sensor was operated from an elevation of 20 metres, these bias settings were found to be too low. This was recognized by large swings in the ratio channel output during platform leveling operations or different sea state conditions.

During operation when the water surface was very flat, the sensor was found to be extremely sensitive to sensor orientation. If proper sensor orientation was not maintained, the reflected beam would be reflected completely out of range of the receiver. As signal levels for channels 2 and 3 decreased, the ratio channel output would go off scale since the bias settings were too low.

The sensor did perform well in chop which was at all times less than 0.3 metres in height. Although signals were usually low when operating at a height of 20 metres, the sensor did respond to oil. Chart recorder output typical of choppy conditions is given in Figure 29. Note the relatively high baseline around 2.0 volts. Although maximum response to oil is off scale, it is at least double the voltage of the clean water situation.

The performance characteristics and limitations of the sensor under various wave conditions is summarized in Table 8. The sensor was shown to be effective when operating from heights of 10 and 15 metres. By correct setting of the bias controls, accurate and reliable detection of oil slicks is anticipated at the 20 metre height.

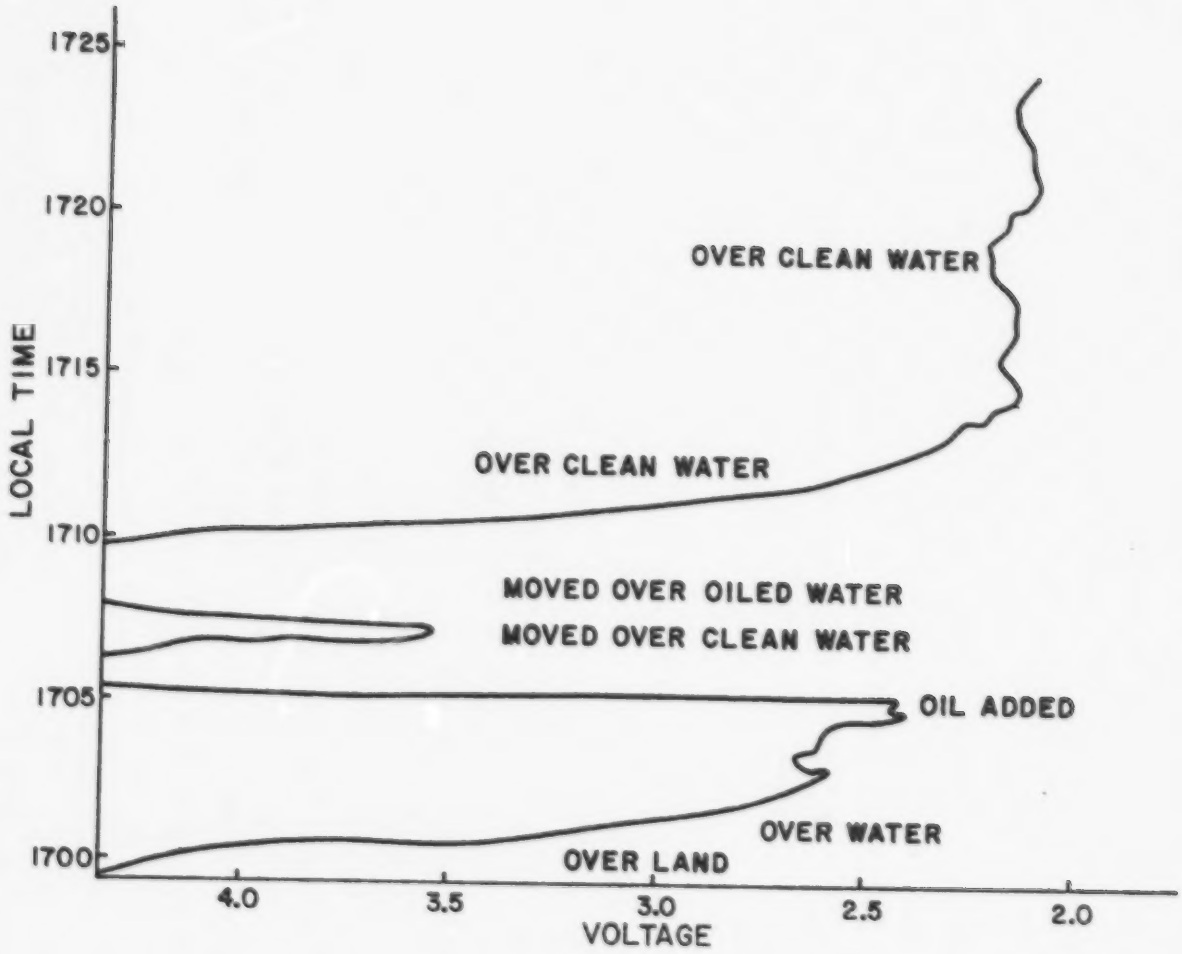


Figure 29. Ratio Channel Output from Infrared Oil Film Monitor

Platform Height	20 m
Winds	NW 15 knots
Sig. Wave Height	0.3 m
Skies	Clear

TABLE 8

SUMMARY OF WRIGHT AND WRIGHT SENSOR CHARACTERISTICS

UNDER DIFFERENT WAVE CONDITIONS

Wave Height	Comments
Flat water	Sensor orientation critical. Strong signal received if sensor properly orientated. No signal received if sensor off vertical. Can detect oil from at least 20 m above surface.
Swell	Expected performance: sensor orientation not critical. Signal strength will vary greatly. Average signal strength will be weak since reflected signal is often completely out of range of the receiver. Sensor footprint should have diameter on water surface as large as one-half the distance between wave crests. Should be able to detect oil.
Chop	Sensor orientation not important. Received signal is weak but consistant. Can detect oil from at least 15 m above surface.
Breaking waves	Expected performance: may be difficult to detect oil since oil film is not continuous.

6.2 Barr and Stroud Thermal Imager

In the thermal infrared region, oil is not identified from water by a steady or absolute difference in apparent temperature. Rather, it is the relative differences in appearance due to processes such as solar heating, emissivity, etc., that result in oil being distinguishable from water. A synoptic view of both oil and clear water is therefore required for positive identification of the oil. The configuration of the Barr and Stroud Thermal Imager was not optimal for the field program because of the unit's small field of view. It came equipped with a telescope which had a maximum field of view of only 15.4 degrees by 10.2 degrees. At a 20 metre operating height this provided a ground coverage of 5.4 metres by 3.6 metres. During the field evaluation, when small quantities of oil were released onto the water surface, the oil would drift out of range quite quickly before coming into complete thermal equilibrium with the surrounding environment. As a result, little useful thermal IR data was collected during the oil release events.

Most of the signficant thermal IR data was obtained when the platform was situated directly over the oil retaining boom. In this situation, the oil film could be seen inside the boomed area whereas clear water was present outside the boom.

A sample of the IR Imagery is shown in Plate 2. The imagery was taken on 29 November 1985 at 2030 local time. The skies were clear at the time with an air temperature of 6°C, water temperature of 1°C and winds from the NNE at 22 km/hr. The photo shows oil to the right of the boom and clear water to the left. The oil boom has been preferentially heated on the left side due to the low altitude of the sun. The oil appears warmer than the water, probably due to the solar heating. The oil is thicker along the boom since the wind is moving from right to left in the photograph. A number of warm features are present on the left side of the boom. These represent small amounts of leakage of oil underneath the boom.

It should be noted that plate 2 is a photograph from a television monitor and therefore suffers from a serious decrease in overall picture

Plate 2. IR Imagery - November 29, 1985

quality. The dynamic quality of the original imagery is also lost which further degrades the effectiveness of the plates.

Imagery taken of clean water had features similar to those seen during the tower tank tests when a fan was used to agitate the water surface. The dark wispy features, believed to be areas of concentrated evaporative cooling were most evident during low wind conditions when the water surface was barely rippled. As rippling became more intense and waves started to build, these features would be replaced by larger scale features which were the result of surface mixing. These would be most prevelant in breaking waves where large thermal differences between surface and subsurface waters would be clearly evident. This excellent detail of surface thermal conditions was the result of the high sensitivity of the detector, high resolving power of the telescope, combined with low operating height. When oil was added to this intensely detailed and contrasty image, interpretation was made difficult and often impossible.

The best conditions for detecting oil with the IR imagery included operation in the early afternoon with winds less than 5 knots, no waves and clear skies. During these conditions, the oil would be clearly observable as a continuous warm area. Swell conditions were very similar to that of clear water.

A slight chop on the water surface would dramatically alter the oil detection capabilities of the sensor. The oil film would become broken and the rapid mixing of surface waters, subsurface waters and the oil film would confuse the image. Typical imagery taken during these conditions exhibited great contrast with many rapidly moving and changing features which were impossible to interpret or quantify.

Large chop and breaking waves agitated the oil film sufficiently that oil was dispersed in the water column and therefore retained the temperature of the water. In this situation, solar heating of the slick was not significant and the oil would appear cool if seen at all. The diesel and crude oils were not detected when released into breaking waves. The only situation when oil was seen in breaking waves was when quantities

of oil taken from the separators were released in the sensor's field of view. In this situation, the oil formed into bouyant globules that could be seen as cold areas within the breaking waves.

During nighttime operation of the infrared imager, when crude and diesel oils were released onto the water surface, they were seen by the infrared imager but primarily because they retained their source temperature. The quantities of oil released drifted out of range of the sensor before the oil had the opportunity to come into complete thermal equilibrium with the environment. Oil which was warmer than the water when introduced remained warmer. Similarly, oil which was colder than the water when introduced remained that way, at least until out of range of the sensor.

Oil already present within the boomed area was observed several times at night but verification of extent and thickness of the slick was difficult at night. Heavy concentrations of oil were the easiest to observe and verify. These areas appeared warmer than the water at all times, probably since they inhibited natural evaporative cooling of the water. Thermal conductivity differences between the oil and water may also have been important. Although heavy oiled areas were detected, their contrast at night was much less than that which occurred through the day.

Thin oil films were much more difficult to positively identify with the infrared imager. Thin oil films do not coalese or dampen wave action as effectively as thick oil films. As a result, they tend to be discontinuous even under small wave conditions. This makes interpretation and verification of the imagery much more difficult if not impossible. Sufficient contrast between the oil and the water may be present for thin films, but an additional means of verification is required.

A summary of the appearance and detectability of oil in the thermal infrared region during the field tests is given in Table 9. The observations are based only on tests results and may be different under different environmental conditions and when using different oil types and concentrations.

TABLE 9

APPEARANCE OF OIL FILMS IN THERMAL IR

Water Surface Conditions	Water	Oil	Comments
Sheens			
Calm (daytime)	cold	hot	due to a combination of factors
Calm (nighttime)	no significant difference		film too thin
Chop	no significant difference		film too thin
Breaking waves	no significant difference		film too thin
Slicks			
Calm (daytime)	cold	hot	due mainly to solar heating
Calm (nighttime)	cold	hot	oil may not be visible at times; depends on a combination of factors
Chop	cold	hot	positive identification depends on slick being fairly continuous
Breaking	hot	cold	oil cold due to lower emmisivity; probably not observable except at close range with heavy oil
Chop and Breaking (nighttime)			oil not differentiated from water

6.3 Moniteq Oilspills Vapour Sensor

Judging from the performance of the Oilspills at the tower tank, poor performance was expected from the Oilspills sensor during field testing primarly because the vapour concentrations were expected to be much lower in the field since winds would quickly transport most of the vapours away from the slick, especially if the slick was small. Interferences are also a problem in the field and at this site in particular: fugitive vapours from various refining processes are prevelant at the site and could contaminate test results.

Figure 30 is a sample of Oilspills data taken at the refinery on 6 December, 1985. As indicated on the plot, two small oil spills were created. The 750 mL diesel spill corresponded with a slight increase in gas signal. From previous performance of the sensor, it is improbable that this increase was the result of the oil discharge. The spill of 200 mL of motor oil also corresponds with a slight peak, but again, the peak is within the noise level of the sensor.

Slightly later, a tanker truck discharged a load of used oil into the seperators. Considerable vapours were evident at the site for approximately 15 minutes. A significant increase in gas signal is evident but it is presumed to be a direct result of a change in radiance signal.

Most of the data obtained during the field testing of the instrument was similar to that obtained in Figure 30. Noise levels were quite high and it was difficult to relate instrument response to oil vapour concentrations. The sensor did not respond to ambient oil levels inside the boom but this was not surprising given the non-volatile nature of the oil. A number of intentional releases were conducted directly below the sensor but no positive response was registered by the instrument. Diesel crude and even gasoline were tried but none were able to elicit a significant response. A variety of operating heights ranging from 5 to 15 metres were used but none appeared to improve oil detectability.

On 11 December in an attempt to verify correct sensor operations,

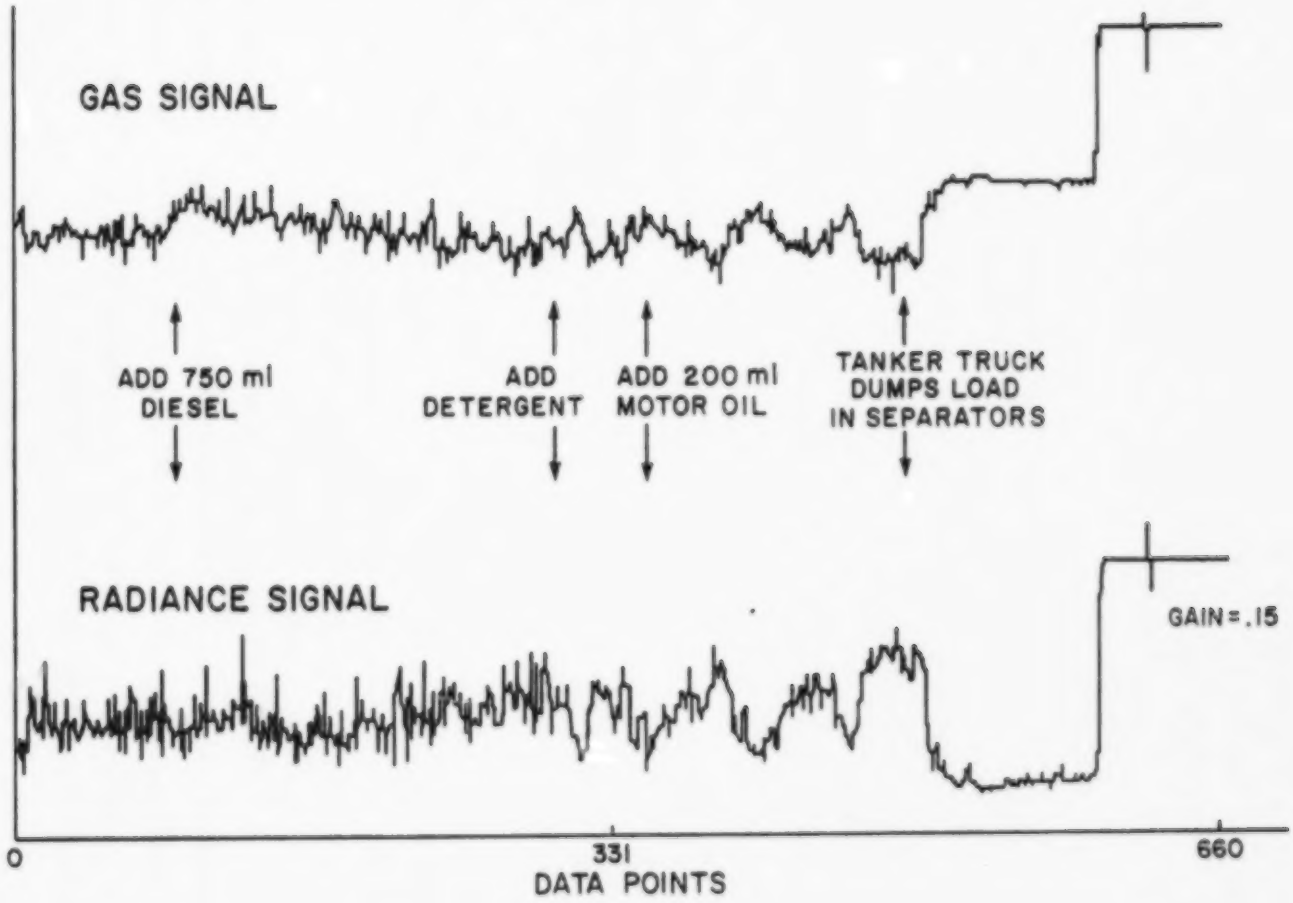


Figure 30. Oilspills Output - December 6, 1985

the Oilspills was mounted one metre above an open plywood box. The instrument was allowed to equilibrate with the surrounding environment for 15 minutes over which time the gas signal went through a large negative, then positive cycle. Small amounts of propane were then introduced into the plywood box beneath the sensor. Instrument response is evident in Figure 31. Seven 1 second blasts of propane are clearly shown followed by a 30 second blast.

It is difficult to draw conclusions from the field testing of the Oilspills sensor. The response to oil, if present at all, was not significantly larger than noise levels. The instrument required at least a 15 minute warmup period over which time gas signals varied widely. Radiance changes were also seen to produce large swings in gas channel output. The instrument did positively identify propane but these tests were only run at very low operating heights.

The Oilspills sensor and associated support equipment operated without mechanical problems during the outdoor testing. The processor was found to be somewhat temperature sensitive. Several times after being left out overnight the unit's circuit breaker was thrown on start-up. This proved to be only a minor inconvenience and was resolved by keeping the processor unit in the heated trailer until required. The dewar containing liquid nitrogen lasted approximately 4 hours in the below 0°C temperatures experienced at the site.

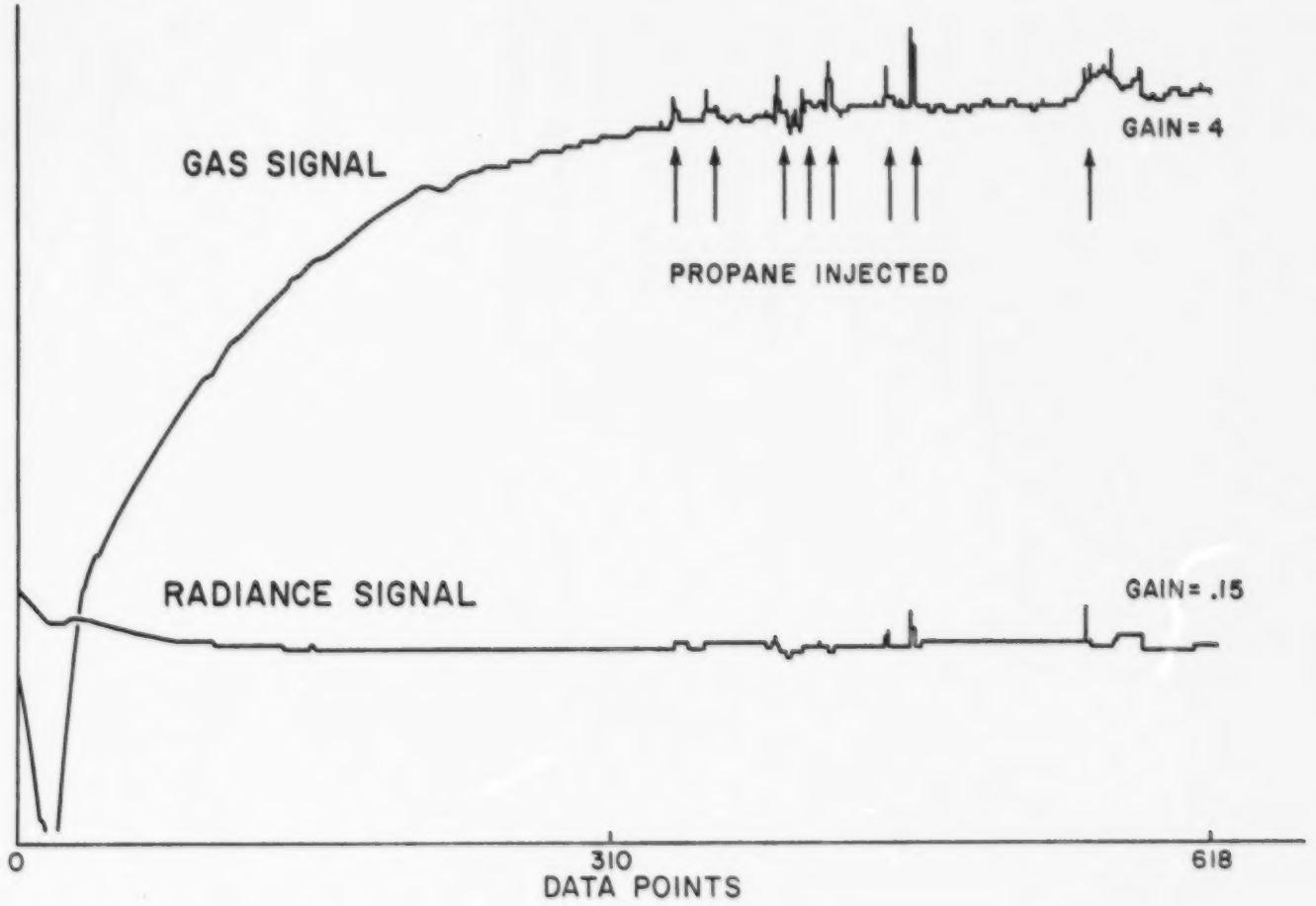


Figure 31. Oilspills Output - December 11, 1985

7.0 CONCLUSIONS

7.1 Wright and Wright Infrared Oil Film Monitor

The sensor was found to be completely effective when operating from a height of 15 metres. A low baseline over clean water was maintained at all times. Oil films produced a sudden and significant response sufficient to trigger an alarm. The sensor triggered alarms on very thin films but did require that the oil film be fairly continuous.

When operating from a 20 metre height over clean water, the baseline was affected by surface wave conditions. The larger the waves, the higher the background signal. Response to oil above the background condition appeared to be in rough proportion to the magnitude of the background signal already present. Although it was obvious from the chart recorder data when an oil film had occurred, a preset alarm level could not have been selected and expected to work under all surface wave conditions.

The Wright and Wright monitor was the only sensor tested which was specifically designed for continued surveillance of oil films. As such, it already contained many of the features that would be required by an offshore monitor. Possible shortcominings of the monitor relate to operating height, sea surface conditions, and the limited selectability of the alarm conditions.

7.2 Barr and Stroud Thermal Imager

The configuration of the imager, as tested, was not well suited for long term deployment. The high pressure air bottle required recharging every 8 hours with ultra-pure air. The telescopic lens permitted only limited areal coverage. Since oil is detected by determining a contrast in an image, the areal coverage of the sensor should include both the oil film and a clean water surface. With the telescope used, often clean water areas or oiled areas would completely cover the sensor's field of view. In these situations, it was not possible to define the surface as either oil or water.

In most situations, the Thermal Imager had sufficient sensitivity to detect apparent temperature differences between the oil and water. However, positive identification of slicks was often difficult. Oil may appear either warmer or cooler than the water, depending on the environmental conditions present at the time of the imagery. Mixing of surface and subsurface water of different temperatures by wave action, acts to further complicate the interpretation of the imagery. Additional information is usually required before positive identification of the oil may occur. For these reasons, alarm monitoring in the presence of oil slick will be very difficult.

7.3 Moniteq Oilspills Vapour Sensor

The sensor, electronics and data storage and display devices require considerable space and numerous cables. Real-time interpretation directly from the television monitor is difficult since only 8 data points are shown; effective data analysis required storage of raw data on diskette which was then outputted as computer plots. The dewar containing liquid nitrogen requires re-filling at 3-4 hour intervals which was found to be time consuming and logistically difficult.

The Oilspills sensor could not identify oil slicks. There were two fundamental problems: excessive background noise and low sensitivity. The instrument requires a considerable warm-up period and even after warm-up, large swings in signal levels occurred. Changes in radiance resulted in sudden and large changes in the gas signal level. Interpretation was very difficult due to the high and variable background, compounded by the fact that oil vapours may produce both increases or decreases in gas signal level.

Furthermore, the instrument is not sufficiently sensitive to vapours emanating from oil spills. Spills of both diesel and crude were tested in a field situation and under controlled conditions. In the tower tank, concentrated oil vapours were created, especially when a heater fan was used to induce oil evaporation. Even this situation failed to produce a significant and identifiable response.

8.0 RECOMMENDATIONS

Further testing of the Barr and Stroud Thermal Imager is not recommended. Although the Thermal Imager can define oil films under most conditions, a means of verification is almost always required. Furthermore, design of an effective automatic alarm system utilizing the video output from this device would be difficult and probably prove unreliable. The Barr and Stroud Thermal Imager should continue to be used in oil surveillance sorties, but not relied on for sentinel oil monitoring.

The Oilspills vapour sensor in its present format is not able to detect oil films on the water surface. The sensor should be re-evaluated with effort focused on determining exactly what constituents of an oil slick the sensor is detecting, and whether these constituents are evaporating from oil slicks in sufficient quantities to be detected. Other considerations should include reducing the effects of radiance changes on the gas channel output, and the design of a real-time plotting program for the microcomputer. Development of an effective operators manual detailing the exact operating theory of the sensor is considered imperative. A modified Oilspills sensor must show adequate results during laboratory tests before any further outdoor testing is considered.

The Wright and Wright Infrared Oil Film Monitor was judged as a successful sentinel device and warrants evaluation in the offshore. The recommended study would involve short term deployment of the instrument at an offshore platform, during which time a number of controlled spills with non-toxic oils (e.g., vegetable oil) would be undertaken. Construction of a suitable housing for offshore deployment would be required. Digital processing of the data should be considered since this would permit sampling only where there was sufficient signal return, which would in turn, compensate for variations in water surface conditions. A small field of view combined with more highly focused lamps may permit operation at higher elevations and should also be considered.

We judged laser fluorosensing to be the best alternative to the Wright and Wright sensor, should that device prove inadequate in the offshore.

A brief discussion of a possible sensor system and recommendations concerning preliminary work are included in Appendix A.

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APPENDIX A

Design of a Laser Fluorosensing System for Deployment on Offshore Platforms

Design of a Laser Fluorosensing System for Deployment on Offshore Platforms

Introduction

Section 2 of this report identified laser fluorosensing as a particularly effective method of oil detection. Although various airborne systems had been built, no suitable systems have commercially been available for chronic oil discharge monitoring. Since this method of detection appears to offer great potential, it was decided to undertake a preliminary study into the design of a suitable system. Scintrex Ltd., a world leader in laboratory and medium range laser fluorsensors was contacted and a brief proposal for the design of a suitable system was formulated.

The solution proposed herein is essentially a rugged laser fluorosensor, adapted to perform in the marine environment. The instrument must operate about 30 metres above the nominal sea surface and must cope with rapid, large variations in range to target. In order to work reliably at sea, the instrument must be packaged in a very strong container. In addition, the optical nature of the instrument requires that the package have some unusual characteristics, principally that it include a window which is automatically kept clean when subject to spray and wave action.

Detection of Oil by Fluorescence

Oil films fluoresce under the influence of ultraviolet excitation. The emission spectra reported in the literature are broad band types, peaking in the 450-500 nm. region. Figure 1 shows a selection of spectra for crude and refined mineral oils. When a fluorescer is excited by a very short pulse of light, fluorescence continues for a finite time after the cessation of excitation. The time required for the emission intensity to decay to 1/e of it's original value is referred to as the lifetime of the fluorescer. Oils have lifetimes of the order of 10 nS. A rough correlation of emission wavelength and lifetime has been noted in crystalline minerals; a similar phenomenon occurs in crude oils. As any crude is a mixture of components, at any particular wavelength one or more components may be observed so, a range of lifetimes will be determined across the emission spectrum. Figure 2 shows a plot of "fluorescence decay spectra" illustrating this phenomenon (Measures et. al. 1974, quoted in Measures 1984).

Figure 3 shows a typical oil emission spectrum and a seawater spectrum. There are clear differences in the shapes of the spectra. In addition, oil is a much more efficient fluorescer. Table 1 shows data for the fluorescence efficiency of a number of oils (Fantasia & Ingrao 1974).

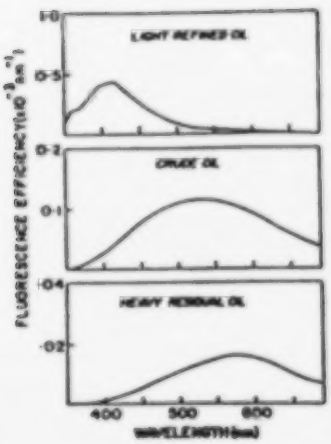
The detection limit of a fluorescer is controlled by its fluorescence efficiency and by the noise level associated with the measurement. It is possible to measure and null out the large DC signal produced in a photodetector by ambient light. The noise in the ambient measurement cannot be nulled however. The noise current in a measurement of a photoelectric current i_b for a time period T is given by

$$i_n = \sqrt{2\ e\ i_b \Delta f}$$

where Δf is the noise bandwith, 1/T.

A calculation of the probable signal to noise ratio of a simple fluorosensor demonstrates the feasibility of the instrument.

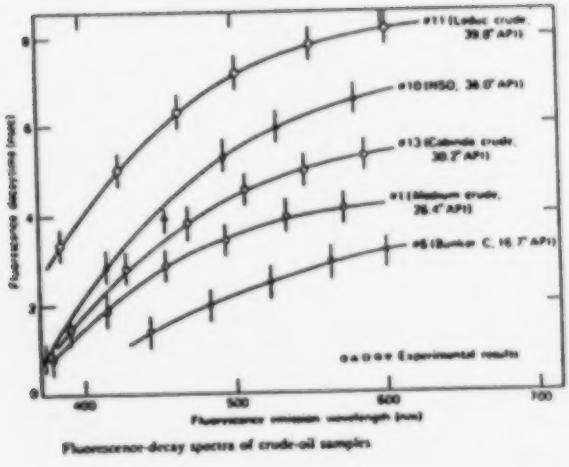
Take the distance to target as 30 metres, and assume the sea surface is being examined using a telescope with a 20 cm. aperture, equipped with an optical bandpass filter which transmits from 450 to 500 nm, hypothetically with unity transmission. The size of the imaged region would be of the order of 100 cm^2. Using the solar spectral irradiance data quoted by Measures (1984) for the region 450 to 500 nm., 0.15 watts cm^{-2} $microM^{-1}$, we obtain a figure for the total solar power in this band falling on the target of 0.75 watts. The reflectivity of seawater in this region is probably of the order of 10%, thus the power available for capture by the telescope is 750 mW. The telescope will intersect only a portion of the radiation; taking the ratio of the telescope aperture to the surface area of a sphere 30m in diameter, we obtain a value of 3×10^{-6} for this factor. Thus, the power falling on the detector is 0.225



Typical emission spectra of oils from the three main oil groups: light refined products, crude oils, and heavy residual oils (O'Neil et al., 1978).

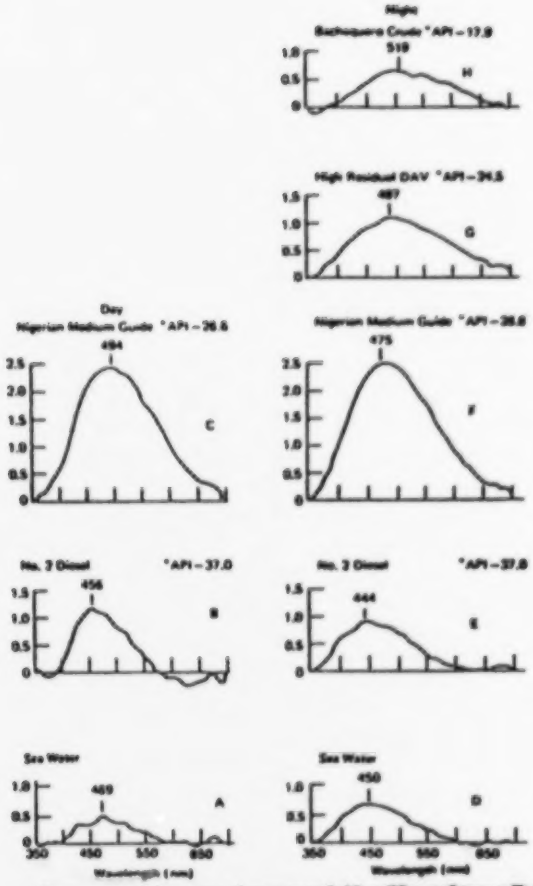
Figure 1. Oil Fluorescence Spectra

Taken from Measures' 1984 book.



Fluorescence-decay spectra of crude-oil samples

Figure 2. Fluorescence Decay Spectra. Taken from Measures' 1984 book.



Fluorescence emission spectra of sea water and of four different oil types spilled at sea as measured by the Transport Systems Center (Cambridge, Massachusetts experimental airborne laser oil-spill remote-sensing system during field test (Fantasia and Ingram, 1974).

Figure 3. Oil & Sea Water Spectra. Taken from Measures' 1984 book.

microwatts. A typical photomultiplier has a cathode sensitivity of 50 mA W^{-1}; the photocurrent due to ambient light will be about 11 nA.

The lifetime of oils is of the order of 10 nS; if the ambient light signal is integrated for this time, the associated noise current will be given as

$$i_n = \sqrt{2.e.11\times10^{-9}/10^{-8}} = 0.6 \text{ nA}$$

The excitation source for the proposed sensor is a nitrogen laser which produces 250 microjoules/pulse. The average fluorescence efficiency of the crude oils studied by Fantasia & Ingrao (ibid.) is 3.8×10^{-4}. A simple model of the fluorescence process assumes that all the laser energy is absorbed by an area coincident with that observed by the telescope (100 cm^2). The energy released in fluorescence is thus about 9.5×10^{-4} microjoules cm^{-2}. Of this total, a factor (1-1/e) = 63% will be released in the first 10 nS. Making the simplifying assumption that the energy is released linearly, the fluorescence power density is 60 mW cm^{-2}, and the total power is 6 watts. If this is observed with the same telescope as the ambient, the power falling on the detector/ filter assembly due to fluorescence is 18 microwatts. The bandpass filter referred to above rejects part of the fluorescence emission spectrum; it will allow about 10% of the power through to the detector. Hence, the photocurrent due to fluorescence will be about 90 nA.

The signal to noise ratio indicated by these simple calculations is 150. A factor of 5 should be allowed to account for electronic and other noise sources not included above. The transmission of the optical components has not been considered in the calculations. Assuming a figure of 20% for the overall transmission, a final anticipated signal : noise ratio of 6:1 is obtained. This is adequate for the purpose envisaged.

The detection limits may be improved futher by stacking the results of a number of measurements. If n measurements are made, the signal to noise improvement may be expected to be a factor $\sqrt{n}$. Thus, stacking 100 of the measurements would give a signal : noise of 60. The laser repetition rate is about 15 s^{-1}; a set of 100 stacked measurements would take 7 seconds.

Antecedents

Scintrex have considerable experience in the design of optical equipment for use in adverse environments. Developments pertinent to this proposal are:

The UA-3 a time resolved fluorometer used to measure ppd and sub ppb levels of uranium in solution. This instrument incorporates a novel sealed nitrogen laser, the first of its kind to be commercially available. The UA-3 has been in production for ten years, it has been used in uranium exploration and processing and is finding increasing use in materials quality control, effluent monitoring and health & safety testing.

The MU-4, an automated version of the UA-3 designed as a multi-stream process control analyser for uranium mills. This device is designed to run unattended for extended periods of time and to provide alarm and monitoring functions to plant operators who are not skilled in chemical analysis.

The LMX-1, an airborne fluorosensor designed to detect fluorescent minerals from an aircraft. This instrument incorporates LIDAR and ambient light nulling techniques which are pertinent to the design of an oil spill sensor.

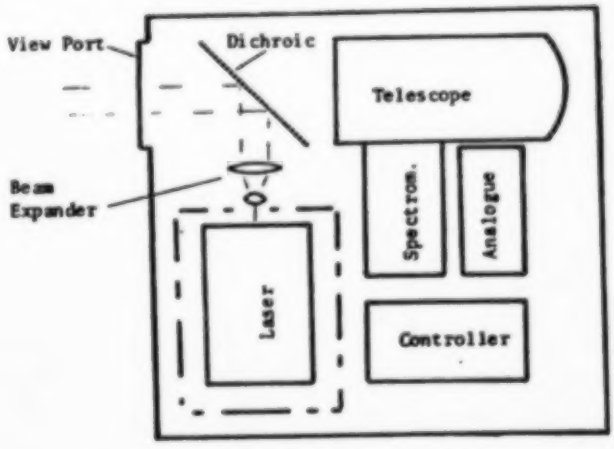
Certain aspects of all these instruments would be incorporated in the oil spil sensor. The laser would be taken from the UA-3, the ambient and LIDAR section from the LMX-1 and the software philosophy from the MU-4

Fluorosensor Design Outline

The basic design of the fluorosensor is shown in figure 4. The excitation source is the sealed nitrogen laser developed by Scintrex for use in the UA-3 Uranium Analyser. The emission spectrometer consists of an imaging system based on a commercially available telescope and a spectrometer similar in design to many stellar photometers. The spectrometer will have two or three channels defined by bandpass filters. The detectors will probably be photomultipliers; this type of detector has proved reliable in such systems in the past, it provides both high gain and good temporal response. Timing control and laser intensity monitoring are provided by a photodiode which receives a portion of the output beam diverted by a beamsplitter.

A block diagram of the instrument operation is shown in figure 5. The sequence of events starts with a measurement of the ambient light level in each channel of the spectrometer. This ambient level is subtracted from the fluorescence data captured after the laser fires. The laser is fired; all subsequent timing is refered to the start of laser emission as monitored by the photodiode. Some finite time after laser emission a signal significantly above the ambient level is detected by the first photomultiplier. The time difference is used as a measure of the distance to the sea surface. Sample and hold circuits are used to measure the fluorescence intensity at a time after the first return chosen to optimise both sensitivity and reliability. Several sets of sample & hold circuits may be used to exploit the variation of lifetime with wavelength described by Measures et. al. (ibid).

The data for each shot will be normalised to a standard range; experience with the optical system of the LMX-1 shows that the variation of overall response with range for such a device obeys a law between $1/r^2$ and $1/r^3$. Data taken from extremely long or extremely short ranges would be rejected as unreliable. The results of a number (e.g. 32) of shots would be stacked to improve signal to noise ratios. Each set of stacked data would be compared with both pre-assigned trip levels and with recent historical data to detect sudden changes.



Date	Rev.	Zone	Description	By	Appd

SCINTREX

Dsig.	Drawn by	Checked by	Assembly
Material			Scale
Finish			

Figure 4. Fluorosensor for Oil Spill Detection.

Model No.

Size | Dwg. No.

DO NOT SCALE DWG.

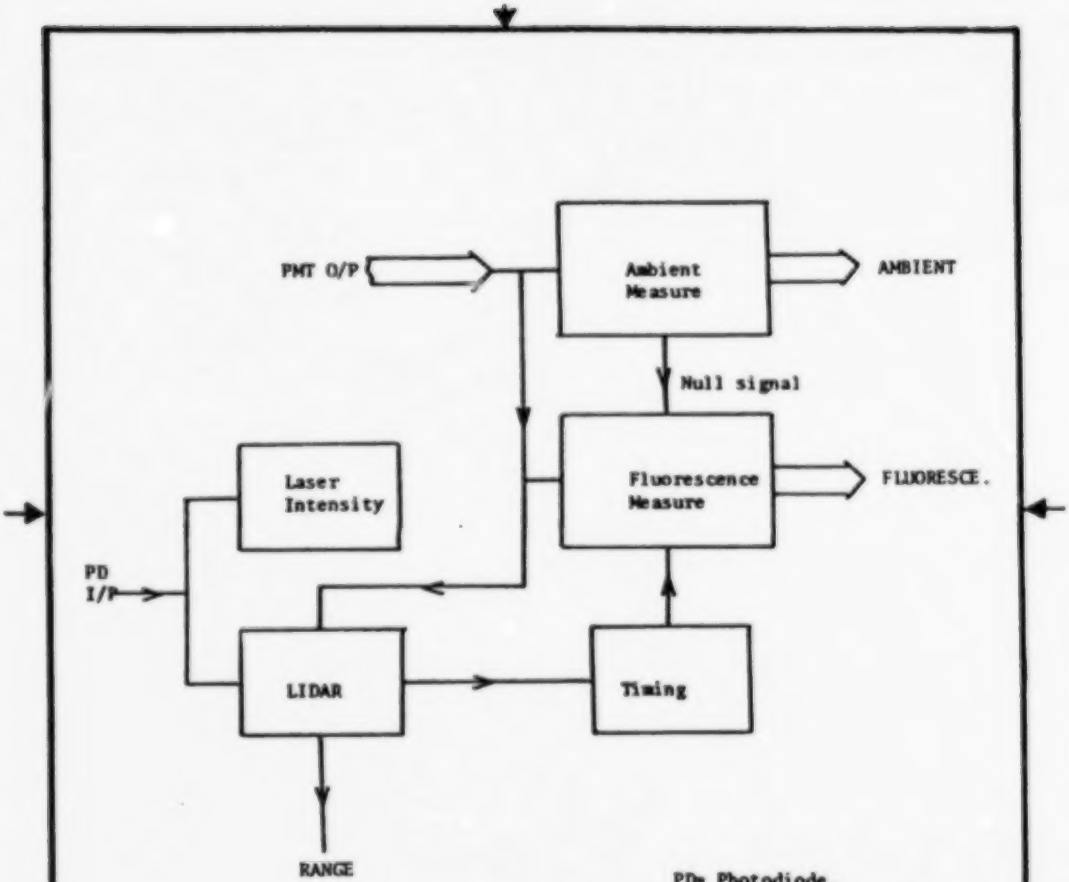
Data Presentation

The form of data presentation used would be chosen in consultation with end users . Either a simple alarm could be implemented, or a more complex display of data could be provided. The data available for inclusion in a relatively elaborate display include:

1. Fluorescence intensity for both present and historical data sets. These could be expressed as equivalent oil concentration

2. Range/Waveheight data derived from the range to target information.

3. Ambient light information. This is valuable as a guide to the noise level to be expected in the instrument.



Date	Rev.	Zone	Description	By	Appd

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SCINTREX

Date	Drawn by	Checked by	Assembly

Material

Finish

Scale

Dimensioning in Inches / mm

Tolerances unless otherwise specified

Inches	mm	Surface condition
X ± .XXX		
.XX ± .XXX	Angles ± 0° 0'	Sharp edges and break sharp edges
.XXX ± .XXX		

DO NOT SCALE DWG.

Title: Figure 5. Oil Fluorosensor Operational Block Diagram.

Model No.

Size | Dwg. No.

330821

Perimeter Sensing

The instrument described above has a fixed optical axis and would view a fixed area of the sea surface. Any requirement for measuring a swath along the side of a platform could be met by simply swivelling the complete instrument. The package is expected to be quite small (say 80cm x 50cm x 50cm) and could readily be mounted on a suitable mechanical drive. In comparison to articulating one of the optical elements, simple movement of the complete system seems preferable.

Potential Problem Areas

1. Environmental

As a downward-looking optical system is to be mounted only thirty metres above water level, there will be obvious problems in keeping the laser/telescope windows clear. Some type of rotating window or wiper device, and possible a washer will be required. Alternatively, air curtains provided by comparatively high volumes of air at low pressure blowing across the windows might aid in keeping sea water from reaching the windows. An early component of a design programme would be a literature search and review of similar requirements for optics in a marine environment and the means taken to solve them.

The remaining problems of humidity, ambient temperature variations, electrical connections etc. are common to all marine equipment and appropriate techniques and materials are available.

2. Specularly Scattered Light

At a given combination of sun angle, wave slope and instrument orientation, sunlight will be reflected into the telescope receiver. Provision will have to be made to reduce the photomultiplier high voltage supply very rapidly to avoid damage to this detector. Various electro-optical shutters are also available, but their transmission in the nominally "on" state is usually quite low.

3. False Alarms

It seems likely that there would almost always be a thin film of oil around a drilling or production platform, if only from the workboats, tenders etc. If this is the case, it would need to be shown that the fluorescent response arising from a leak on the platform is substantially different from the more or less "normal background". The close monitoring of this background will be necessary in order to generate correct procedures for detecting anomalous events.

Proposed Development Schedule

The development of a fully functioning oil spill sensor is expected to follow this path:

1. Initial sample tests to prove measurement is indeed possible. Compilation of oil spectra and lifetime data. Definition of operating specification for final instrument. This phase would be completed in about 1 month.

2. Optical & electronic design of prototype. Includes selection of spectrometer channels and time regime. Off-the-shelf components will be used where possible. Housing design in collaboration with experienced marine engineers.

3. Definition of data system. First draft of software.

4. Prototype testing at a suitable facility.

5. Implementation of changes required by test results.

6. Housing of prototype in full environment casing.

7. Sea trials.

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APPENDIX 1 Literature.

Papers on the subject of oil spill detection may be found in commonly available journals, and in the proceedings of specialised conferences. This section will cite a few important references, which should serve to introduce the reader to the field. In particular, Measures' book "Laser Remote Sensing" summarises both the theory and practise of this technology. No attempt has been made herein to provide a comprehensive literature survey, which would, in any case, probably include much material which is not easily obtained. Should the reader find a particular reference unobtainable, copies may be available for loan from Scintrex' library.

Remote detection of oil films by various methods has been discussed by numerous authors. Estes & Senger (1972) considered multispectral sensing of such films in the microwave, infrared and ultraviolet regions. Laser fluorosensors are described by, among others, Fantasia & Ingrao (1974), Measures & Bristow (1971) and Bristow (1978).

A recent overview of the field of laser remote sensing is given in a book by Measures (1984). The fundamental properties of LIDAR and fluorometric systems are discussed. Their use in water quality monitoring is covered, although no mention is made of analogous uses to detect solid materials (e.g. Robbins & Seigel, 1985).

Most of the published work in the field was performed in the 1970s. The emphasis was upon forensic uses of the technology; detecting and analysing oil spills in order to find their source and, presumably, the parties responsible.

APPENDIX B

Field Notes and Listings of Recorded Data

FIELD NOTES

Friday, 22 November 1985

The Barr and Stroud, Oilspills and 35 mm camera are installed on cage in tower tank. Video recorder, chart recorders, monitors and micro-computer mounted and connected via cables to cage. Mounts for Wright and Wright prepared and fixed to cage for rapid installation of Wright and Wright sensor once it arrives.

Sunday, 24 November 1985

Personnel from Wright and Wright, and Moniteq arrive in Halifax. Wright and Wright sensor installed on platform and Oilspills data processing programs tested. Everything prepared for early start Monday morning.

Monday, 25 November 1985

0830 Arrive on site. Run various tests.
1433 Water temperature 14.5°C
Lighting 6.29 tank
8.47 boom
14.53-15.62 near end
Start tape recorders

1441 Add 0.2 mL of diesel oil - diesel oil does not spread out but forms lenses about .8 m in diameter.

1447 Add 1.8 mL more diesel

1500 Add 3 mL more diesel

1507 Generate artificial waves.

1521 Slick underneath Wright & Wright sensor. Add 10 mL which forms into oil lens about 2.0 m in diameter.

1532 Conclude tests.

2038 With two lamps on, add 10 mL diesel fuel.

2040 Oil dispersed with soap.

2045 Lamps turned off on Wright & Wright.

2049 100 mL of disel oil added.

2050 Oil dispersed with soap.

2105 Recorders shut off and tests concluded.

Light measurement at water surface level taken with integrating quantum radiometer photometer.

		quanta/cm^2 sec
Bottom of tank with two overhead lights on	center	1.14
	far end	1.01
	near end	1.01
	center of boom	1.08
Bottom of tank with two overhead lights on and three lamps for Wright & Wright on	center of pool	5.34
	center of boom	6.53
	far end	4.13
	near end	15.88
Bottom of tank with three lights from Wright & Wright only	center of tank	4.40
	center of boom	6.30
	far boom	3.05

Tuesday, 26 November 1985

0900 Oilspills, Barr and Stroud, and Wright and Wright all operating.

0925 Start video recorders and chart recorders for Wright and Wright.

0926 10 mL of crude oil added to boomed area.

0930 Air temperature - 14°C
Water temperature - 14°C
Oil not spreading well.

0959 Fan turned on to spread oil over surface. Barr and Stroud detecting oil nicely as a hot area. Camera sensitivity set to one less than maximum. Wright and Wright sensor detecting oil when oil passes through its field of view.

1030 Entire water surface becoming oiled so tank drained and refilled.

1200 Tank refilled. Water temperature - 9°C, air temperature 13.5°C.

1219 Oilspills started recording onto disk.

1228 Recorders started.

1229 10 mL of crude oil at 20°C introduced into boomed area.

1230 Water temperature - 9.5°C
Air temperature - 11.5°C
Air temperature outside port hole - 14°C

1237 Large fan turned on.

1240 Fan turned off.

1242 Re align Wright and Wright.

1245 Turn fan on - crude slick covering 1/5 of area. Wright and Wright detecting oil as oil moves through field of view. Wright and Wright does not detect the very thin sheen. Since it integrates over entire field of view, substantial oil is required unless a uniform slick is present. Barr and Stroud detecting oil as hot area. Some confusion with warm surface water and cooler subsurface water.

1249 Move oil boom outside Wright and Wright field of view.

1252 Move oil boom back inside Wright and Wright field of view.

1300 Turn fan off and mop up oil with absorbant.

1345 Recorders started.

1404 10 mL of diesel oil added.

1405 Air temperature - 12.5°C in tank
Water temperature - 10.0°C

1409 Fan turned on. Air temperature outside port hole - 13.0°C.

1453 Tapes shut off - similar results as previous test with Wright and Wright and Barr and Stroud but Oilspills data inconclusive.

1502 Recorders started.

1503 Add one bucket of ice inside tank.

1527 Boom moved out of Wright and Wright field of view.

1530 Boom moved into Wright and Wright field of view.

1534 Recorder switched off.

1639 Recorders started.

1643 Add ice onto water surface.

1647 Add 10 mL of diesel oil.

1649 Turn fan on.

1650 Air temperature in tank - 12.0°C.
Air temperature outside port hole - 13.5°C
Water temperature 10.8°C

1710 Turn recorders off.

2000-2400 Further testing with Wright and Wright under a variety of oil thicknesses, wave conditions and also some tests to see if foreign objects trigger false alarms.

Wednesday, 27 November 1985

0815 Ice added to cool water.

0830 Water temperature - 11°C
Air temperature outside port hole - 18°C

0855 Oilspills turned on.

0859 Video recorder for Oilspills starts recording. Oilspills also writing to disk.

0903 Hot air gun positioned over tray of diesel fuel in port hole blowing hot vapours into tower tank.

0906 Smell of diesel fuel very evident at top of tank.

0909 Heat gun turned off.

0913 Large fan turned on in port hole to clear tank of fumes.

0917 Smell of diesel fuel at top of tank much less evident.

0922 Smell of diesel fuel at top of tank nearly absent.

0937 Hot air gun positioned over top tray of crude oil in port hole blowing hot vapours into tower tank.

0943 Hot air gun turned off.

0945 Very slight smell of crude oil at top of tank.

0950 30 second shot of propane from propane torch into bottom of tank.

0952 20 second shot of propane.

1000 Water temperture - 11°C
Air temperature at top of tank - 13°C
Air temperature at bottom of tank - 13°C

1030 Dismantle all equipment for transport to Dartmouth Refinery. Wright and Wright sensor and associated equipment will remain for further testing in afternoon.

1300-1700 Assemble equipment at Dartmouth Refinery. In Halifax, the Wright and Wright sensor was calibrated for optimal performance under wave conditions.

Thursday, 28 November 1985

0830-1600 Install Wright & Wright sensor on mobile platform and connect data acquisition systems.

1630 Start test run to assure all systems are working.

1705 End test run.

1953 Oilspills and Wright & Wright both on. Overcast. Height of platform = 15 m, water temperature 6°C, air temperature 0.5°C.

1957 Move platform to boomed area (over oil).

2000 Move platform to clean area between boom and shore.

2004 Move platform over ground.

2006 Move platform over clean water.

2007 Diesel oil spill (approx. 150 mL).

2011 Move platform over road near API separator.

2014-2021 Move platform over ground.

2028 End run. 13 frames in camera taken. Oilspills data file Nov28_1.1.

Friday, 29 November 1985

0830-1100 Adjust Wright & Wright sensor.

1118 Oilspills test. Full sun, water temperature 6°C, 15 m, air temperature -2°C. Radiance signal (SM) apparently affected by glitter. Wind NNE, 22 km/hr.

1125 Add 150 mL diesel oil.

1133 Add 150 crude oil.

1140 Lower platform to 8 m above spill.

1144 Move platform over ground (height = 1 m).

1148 Place can of crude oil under sensor.

1149 Remove can.

1624 Wright & Wright test. Platform moved to each of 5 positions, separated by approx. 30°. Boomed area includes 60, 90 and 120°. Wright & Wright "footprint" near bottom left corner of Barr & Stroud image. Height = 11 meters.

1625 Move to position - 30°
1627 Move to position - 60°
1630 Move to position - 90' - sunset
1634 Move to position - 120 °
1636 Add motor oil - 140 mL
1640 Move to position - 90° - over multi-colored slick
1643 Move to position - 30° - clean water
1647 Move over slick again - 90°
1650 Wake from tug arriving.
1652 End test.
1946 Wright & Wright test. Air temperature = -5°, water temperature = 6°, full moon.

	Position	CH3 (mV)	CH1 (V)	Picture #
1951	0°	182	1.14	1
1954	30°	182	1.12	
2000	60°	399	3.25	2
2010	Collect 2 Belor samples + 1 for GC analysis			
2012	90°	262	3.12	3
2015	120°	214	1.47	
2017	120°	Add motor oil		4
2018	120°	218	1.88	
2020	120°	Add diesel oil		5
2022	120°	225	1.76	
2023	90°	Move platform		6
2025	90°	253	4.04	
2030	90°	Move closer to dock		
2031	90°	755	3.68	

Tuesday, 3 December 1985

0900 Arrived at site. Only Wright & Wright switched on. Air temperature = -1°, wind 25 knots from west with snow flurries, waves 0.4 m and 2.5 second period.

0925 Platform moved over water and ratio channel decreased (approx. 70).

0945 Platform brought back to shore and signal went up off scale.

0955 Platform moved over water - no response until 1959 when signal drops down.

1005 Diesel oil introduced into sensor's field of view and signal increased to maximum in about 2 minutes.

1015 Signal decreases.

1030 Leave site leaving Wright & Wright switched on. The signal remained fairly high and at one point exceeded maximum on chart recorder for about 1/2 hour.

1550 Arrived back at site. Brought array in.

1700 Sent platform back out. Wind NW 15 knots, clear sky, platform height approx. 10 m, 0.2 m waves. Oil released under sensor and signal went to maximum. As wind moved oil out of sensor's field of view, signal dropped back.

1720 Good baseline monitored with platform inside of boomed area.

1800 Left site leaving Wright & Wright on and recording. A good baseline was monitored all night.

Wednesday, 4 December 1985

0830 Arrived at site to check instrumentation. Everything operating well so left site. Through the day there was a significant increase in signal which could have boom the result of increased oil inside the boomed area.

1425 Back at site. Wave 0.2 m and platform has tipped about 8°. There has been some condensation on lens of Wright & Wright which may be causing the increasing signal. Turn everything off and leave site.

Thursday, 5 December 1985

0830 Arrive at site. The Oilspills sensor and processor were kept inside heated trailer overnight in attempt to minimize start-up problems that had occurred earlier in week.

0900 Dewar filled with LN_2 and air bottle filled for Barr and Stroud. 35mm camera battery pack dead so this was charged for approximately one half hour before installation.

0930 All equipment mounted on platform. Having difficulty communicating with Oilspills via micro although the video data is coming out clearly.

1000-1105 Many problems with output from Wright & Wright sensor. Ratio channel output appears to be offscale (i.e., larger) both inside and outside the boomed area. Numerous changes were tried such as tilting platform and adding oil but channel output still off scale. Platform then brought in and it was discovered that considerable condensation was present inside window on receiver. This was not anticipated because sensor was left running all night.

1105 Platform put over water to a height of 10 meters.

1107 Recorder for Oilspills and Barr and Stroud started. Sensors looking at clean water outside the boomed area. Waves are approximately 5 cm high. Very calm conditions. Skies are completely clear and air temperature -3°C.

1113 Platform moved inside of boomed area and Wright & Wright signal increased.

1119 Platform moved outside of boomed area and Wright & Wright signals dropped.

1123 Platform moved inside boomed area and Wright & Wright signal increased.

1126 Thickness sample taken with Belore sampler giving representative measurement of oil thickness inside of boomed area.

1132 Approximately 200 mL of oil released inside of boomed area. Barr and Stroud detecting oil nicely as a cold area. Wright & Wright signal increases quite dramatically. Another sample taken with the Belore sampler at the point of discharge but this one discarded because oil slick had already drifted away.

1143 One container (approx. 750 mL) of crude oil added inside of boomed area. This slick drifted out of sensor range before Wright & Wright had the opportunity for a full response. A Belore sampler measurement was taken beneath the sensors - sampler was dipped once.

1150 A higher baseline continued after the crude drifted out of range of the sensors. It is not apparent what is causing the high baseline. Possibly contamination of boomed area.

1150 One container (approx. 750 mL) of diesel released slightly upwind of sensors and allowed to drift slowly through sensors field of view. This is the highest response seen by Wright & Wright yet. Sample taken with Belore sampler at slick. Sampler was dipped twice.

1200 Wright & Wright signal decreases as slick drifts out of range of sensor, but signal does not decrease back to former levels. At the completion of each discharge, the baseline would not return to former levels but stay return to a value somewhat higher than the former baseline. Even though the oil appears to be drifting out of range of the sensors, the released oil must be saturating the entire boomed area.

1202 One container (approx. 750 mL) of gasoline released. Peak on Wright & Wright not nearly as high as peak with oils, although the gasoline did move through the sensor's field of view quite quickly and sensor may not have had time to fully respond.

1206 One container (approx. 750 mL) of diesel oil introduced over 1.5 minute interval in attempt to get large response from Wright & Wright. A good response was recorded but no larger than previous ones.

1220 Platform moved within boomed area to location near dock when oil had to be concentrated by the light breeze. Peak on Wright & Wright is the highest yet.

1222 Wright & Wright has reached a peak and fresh water was poured on surface in attempt to disperse oil.

1224 Platform moved outside of boomed area.

1230 The boom on the aerial platform was extended slightly but this resulted in the platform becoming slightly tilted. When the platform was tilted off of vertical, the ratio channel from the Wright & Wright went very high. This was in complete error since the platform was over clean water. Once the platform was repositioned to the vertical, the signal dropped back to the proper baseline. It appears that if insufficient signal is being received, as occurs when calm water surface conditions exist and the platform is tilted slightly, there is insufficient signal for proper processing.

1254 Platform brought back in and testing completed for that day.

Friday, 6 December 1985

0830 Arrived at site. No wind and water was calm. The Wright & Wright was left operating all night and in morning the platform had tilted approximately 10° off of the vertical. The chart recorder showed a decrease in signal for about 2/3 of the night and then the last 1/3 showed an increase in signal. It is not known what caused this systematic change in signal although the tilting of the platform was certainly partially responsible. As platform was brought back to the level, the ratio channel increased although it went through a rather strange swing (evident on the recorder output). Once platform leveled, signal stablized within reasonable boundaries.

0900 Filled dewar with LN_2 and high pressure bottle with compressed air.

0925 Sent platform aloft to 15 meters.

0945 Fine tuning of platform level.

1000 Dropped platform down to 5m level. At both heights the ratio channel would go completely off scale if platform level was off vertical. When platform was fine tuned, signal dropped back to reasonable levels. One interesting point is that signal levels appear to be very high even at the high altitudes with the platform off vertical. Signal levels is tilted so much off vertical that it is impossible for any signals to be recovered, at which time they decrease rapidly.

1030 Platform swung inside of boomed area. Ratio signal increased but not that significantly, even though there is a lot of oil inside boom. Water is very turbid.

1035 Dispersant added to water surface but not enough to disturb the slick.

1037 Platform moved to an oilier part of the boomed area. Wright & Wright ratio channel increased but still not that significantly.

1045 One container (approx. 750 mL) of diesel fuel added to field of view of sensors. Oil temperature approx. 0°C. The diesel oil was very visible on Barr and Stroud as dark and light areas on water. The oil then spread out to an area that was consistently light coloured.

1050 Belore sampler measurement taken to measure background oil conditions inside of boomed area. Sampler was dipped 5 times.

1055 Detergent added to water surface in sensors' field of view. On the Barr and Stroud, the detergent appears as a hot area which spreads out over water surface. Oil becomes concentrated (oil is cold) near the leading edge of the detergent plume. The Wright & Wright signal dropped back to background levels as the dispersant was added. The oil-free area appears bright on the Oilspills monitor. Note that the water inside the boomed area was very turbid.

1059 200 mL of motor oil added to water surface inside of boomed area. Oil sppears hot on Barr and Stroud probably because the oil was stored inside the heated trailer. The oil produced a good response on the Wright & Wright sensor.

1105 A tanker truck of used oil was dumped into the separators at this time. Considerable vapours are quite evident near trailer. These may be evident on Oilspills output during analysis. No significant change seen in real time output.

1110 Platform raised to maximum height which is approx. 21 meters. The ratio channel from Barr and Stroud increased almost to a maximum as platform was raised, then it dropped back to background levels. A low channel three signal of .065 millivolts measured.

1149 One container (approx. 750 mL) of oil based drilling fluid added just slightly outside of boomed area. The oil spread out to a think uniform slick. The area appears bright on Oilspills monitor. The oil was added over several minutes in an attempt of creating a continuous and longer lasting slick underneath of the sensors. Wright & Wright response was higher than with previous discharges.

1155 Added wood board onto water surface in attempt to get fake return from Wright & Wright sensors even though the boards were thoroughly wetted.

1200 Platform swung inside the boomed area. Thin sheen of oil on water surface.

1207 Added detergent to clear oil from area.

1211 One container (approx. 750 mL) of drilling fluid added but a negative response from Wright & Wright sensor was registered. Most of the oil drifted out of range of sensor within a minute.

1213 Platform moved outside of boomed area but oil sheen present in this area. Some detergent added and the Wright & Wright sensor dropped to a good baseline.

1230 Test concluded. Equipment shut off.

Tuesday, 10 December 1985

0900 Arrived at site. Wright & Wright only sensor turned on. Platform swung a number of times inside and outside the boomed area. A reasonable response but fairly small one.

0930 Left site leaving Wright & Wright switched on.

1236 Arrived back at site. In the three hours since leaving the ratio channel had increased gradually over the entire period. In the last hour, the output experienced large swings of unknown origin. This may be the result of platform tilting or swaying in wind. The wave height is about 10 cm outside of boomed area and 5 cm close to boomed area and inside of boomed area. Wind is from the north at about 5 knots. We are sheltered from most of the wind by refinery. When we arrived back, Channel 3 output was 0.093 volts but this increased to about 0.2 volts when platform was levelled. Likewise, the ratio channel decreased when platform was levelled.

1245 Platform was swung close to the oil boom although it still remained outside of boomed area. In this location waves were approx. 5 cm height. There was a small but significant further decrease in signal.

1300 Platform swung out into the larger waves and signal increased slightly.

1309 Platform brought down and Wright & Wright, and Barr and Stroud removed for shipment back.

Wednesday, 12 December 1985

1230 Arrived at site. Oilspills filled with LN_2 and allowed to warm-up. during a 1/2 hour warm-up the gas signal went from .6 to .4 to .04. It is quite stable at .04. Sensor is approximately 0.05 m above ground looking into large plywood box.

1300 Propane introduced into box approximately 6 different times. Signal would increase to .06 or .07 and the decrease once propane was taken away. Considerable propane was in instrument's path since the plywood box was fairly deep with a small mouth and the propane bottle was left turned on for up to one minute during final test.

1330 Conclude tests and pack up equipment for shipment back to suppliers.

1630 Leave site with all gear.

SUMMARY OF VIDEO TAPE RECORDINGS

Letter Designation	Date	Sensor
A	25 November	Oilspills
B	25 November	Barr and Stroud
C	26 November	Oilspills
D	26 November	Barr and Stroud
E	26 November	Oilspills
F	26 November	Barr and Stroud
G	26 November	Barr and Stroud
H	26 & 27 November	Oilspills
I	28 & 29 November	Barr and Stroud
J	28 & 29 November	Oilspills
K	29 November	Barr and Stroud
L	3 December	Barr and Stroud
M	3 & 4 December	Barr and Stroud
N	5 December	Oilspills
O	5 December	Barr and Stroud
P	6 December	Barr and Stroud

SUMMARY OF DISKETTE RECORDING OF OILSPILLS OUTPUT

Filename	Starting Time
25 November 1.1	14:32
25 November 2.2	20:32
26 November 1.1	09:54
26 November 2.2	12:18
26 November 3.3	13:53
26 November 4.4	14:56
26 November 5.5	16:36
27 November 1.1	08:59
28 November 1.1	16:28
28 November 2.2	19:52
29 November 1.1	11:14
6 December 1.1	10:40
11 December 1.1	13:00